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STORAGE BATTERIES: A REVIEW OF THEIR APPLICATION

By E. C. McKINNON, Member.*

(*Paper first received* 31*st May, and in revised form* 7*th October*, 1939*; read before the* North-Western Centre, 20*th February*, 1940. *The paper would also have been read and discussed before* The Institution *on the* 18*th January*, 1940, *but the meeting was cancelled owing to the war.*)

SUMMARY

The object of this paper is to show the important part played by storage batteries in present-day electrical engineering practice. Many of the applications are surveyed in detail as regards design, purpose, latest improvements and practice, and actual results obtained in service.

Contrary to general anticipation that the national grid would lead to a greatly reduced demand for storage batteries, the grid has given rise, directly and indirectly, to numerous new applications for batteries.

Although the review deals entirely with lead-acid batteries, it is not intended to belittle the importance of other types or to ignore the fact that these types too may be of great practical value in many applications.

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(1) BATTERIES IN SUPPLY UNDERTAKINGS

(a) Storage Batteries for Emergency Lighting and Power in Relation to the Grid

The national grid has now been in operation long enough for it to be possible to determine the effect (if any) it has had on the price of electricity to the consumer, the advantages of inter-supply linking, and the benefit derived by limiting the number of generating stations and the plant in those stations.

The grid has of course multiplied the chances of maintaining continuity of supply by interlinking over wide areas, but international developments during the past year or two must have caused many to regret that the coming of the grid scheme led to the wholesale scrapping of central-station storage batteries, which would have formed a highly dependable form of reserve electric supply.

According to statistics supplied by the Accumulator Makers' Association, the aggregate capacity (at the 10-hour rate) of the batteries removed from central stations during the period 1923–38 was 156 000 000 watt-hours. Even this stupendous figure would be of little avail in public distribution schemes, but who would developed to convert direct current into alternating current to supply the power-station auxiliaries. Claims are made for the mercury-arc invertor in this respect, but the author cannot cite any instance in this country where the invertor is commercially used on an uncontrolled a.c. circuit. Where the opportunity still exists, a strong case can be made for a battery scheme, and when such a scheme is put into operation the results show the capital expenditure to have been justified because, apart from the economies effected, the battery is available for various important duties.

---

* Chloride Electrical Storage Company, Ltd.

Table 2

SAVING EFFECTED BY USE OF STORAGE BATTERY ON PEAK LOAD

Period	Saving on kVA per annum		Losses per annum	Annual charges	Net annual saving,	
	£4 per kVA	£3 per kVA			£4 per kVA	£3 per kVA
	£	£	£	£	£	£
1st 7 yr.	4 760	3 570	250	2 692	1 818	628
2nd 7 yr.	4 760	3 570	250	1 453	3 057	1 867
3rd 7 yr.	4 760	3 570	250	2 114	2 396	1 206
4th 7 yr.	4 760	3 570	250	1 233	3 277	2 087
Average	4 760	3 570	250	1 875	2 637	1 447

An outstanding example of a successful battery installation is that of the Borough of Heston and Isleworth. Mr. S. H. Fowles's report to his Committee cannot be reproduced at length, but the salient features of the report are as follows: The storage battery would be used during times of peak load, and would be of such a capacity as to enable the undertaking to reduce its d.c. demand by 1 000 kW. This reduction of the d.c. demand would result in a reduction of the a.c. maximum demand by 1 190 kVA. The saving in maximum-demand charges would therefore be:—

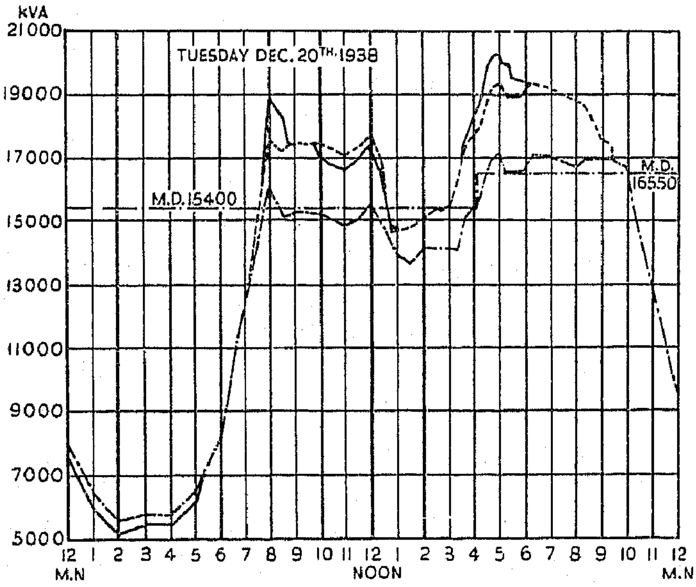

Fig. 5.—Typical 24-hour cycle in mid-winter at Heston, showing part played by battery in reducing maximum-demand charges.

Battery charge or discharge ————
Steam – – – – –
Demand on bulk supply —·—·—

1 190 kVA × £4	= £4 760
less certain losses in working the battery, etc., estimated at 230 000 kWh per annum @ 0·261d.	= £250
leaving a net reduction in maximum-demand charges on the bulk supply of £4 760 less £250	= £4 510 per annum

To show that the battery would still be a paying proposition if the bulk-supply maximum-demand charge were reduced to £3 per kVA, Mr. Fowles prepared the statistics shown in Table 2.

Table 3 shows Mr. Fowles's estimate for the cost of the battery, housing and equipment at Heston. The battery comprises 280 cells with a rated capacity of 2 500 ampere-hours in 1 hour, or 5 000 ampere-hours in 10 hours. Its gross weight is 272 tons, and the floor space occupied, including gangways, is 3 630 sq. ft. The battery was installed at Heston in 1935. So far, the figures of total battery losses (i.e. the difference between

Table 3

TABLE OF ESTIMATED COST, PERIOD OF LOAN, AND ANNUAL REPAYMENT AND INTEREST CHARGES AT 4 %

Apparatus	Estimated cost	Period of loan	Annual payments
	£	yr.	£
Battery	13 500	7	2 230
Building	2 000	30	110
Booster	600	20	44
Switchboards ..	2 200	20	161
Cables	500	25	32
Contingencies ..	200	20	15
	£19 000		£2 592

Estimated life of positive plates 7 years, cost £6 000	= £991 p.a.
Estimated life of negative plates 14 years, cost £4 000	= £661 p.a.
Estimated cost of maintenance	= £100 p.a.

units in and units out, and the consumption of the reversible booster) have been below the estimated amount.

At first it was customary to put the battery on the busbars at a very high discharge rate, and then allow the incoming bulk supply to take the margin. Since then, the evening load has been dealt with by just the reverse process. When the steam sets are started up, they are given their full loading and then the load on the incoming bulk supply is built up to a value slightly below the maximum demand, leaving the battery to take only the peak of the load, which would, without the battery, increase the maximum call on the bulk supply very considerably. This method gives the advantage of an almost full battery ready to take up any extra heavy or unexpected peak for much the greater part of the busy period.

A typical 24-hour cycle in mid-winter at Heston, certified by Mr. Fowles, is illustrated in Fig. 5.

(e) Meter-Testing Batteries

Under the Electricity Supply (Meters) Act, 1936, the Electricity Commissioners require that all single-phase house service meters shall be tested by one of three methods; these methods were described by Mr. Hughes in a recent paper.* Mr. Hughes did not deal with Section (2) of the Act, concerning approved apparatus (for testing stations), including standard potentiometers. Various makers have developed special meter-testing potentiometers with which it is expedient to use storage batteries. There are in each equipment three batteries, the sizes of which have not yet been standardized. Usually, three cells are coupled across the variable rheostat. For the coil of the wattmeter 1–5 cells are employed with a capacity of 300 to 600 ampere-hours, although in special cases the capacity may be 2 000 to 10 000 ampere-hours where absolute constancy of voltage is required, or where current is to be maintained constant to within 0·1 % for 5–10 minutes at the end of an hour's discharge.

For the high-voltage circuit, in which the voltage of the battery must be rather higher than that of meters (say 600 volts), it is preferable to select batteries of 5–10 ampere-hour capacity. Those already in service usually vary from 400 volts to 600 volts.

It is not necessary to provide special work for the high-voltage battery. A prolonged equalizing charge every 3 months, i.e. 5 or 6 hours beyond what is apparently the "full charge" stage, is a suitable cycle, unless the specific gravity has previously fallen to a predetermined minimum.

Large-capacity cells, especially if of the Planté type and if very lightly worked, may require a monthly working cycle unless balanced by a trickle charge during idle periods.

(f) Use of Batteries for Switch Operation and Associated Duties

The best method of using a battery for auxiliary services in a generating station or a substation, is to allow it to supply normally the momentary load, such as switch closing and tripping, and in addition, during an interruption of the main supply, to supply the signalling services and deal with emergency lighting. This practice will give the minimum size of battery and maximum efficiency.

The method of running one pair of common auxiliary busbars along the switchboard and connecting thereto all switch-closing, tripping, indicating lamps, etc., may be modified with great advantage. Any load of a continuous nature, e.g. that required by the signalling system, should be wired on a separate circuit.

The common arrangement might be a rectifier to supply the continuous load normally, including a trickle charge to the battery, the latter floating across the rectifier and supplying the heavy momentary current for switch-closing. Although the closing current may be high, the operation requires only a fraction of an ampere-hour, an amount which can be replaced by trickle-charging. With such an arrangement, care must be taken to ensure that alternating current does not pass through the battery.

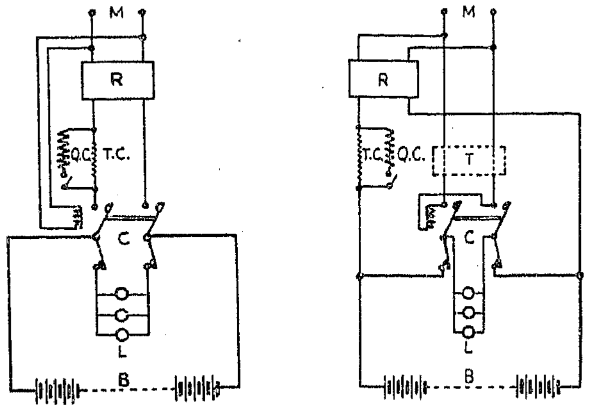

Fig. 6.—Skeleton diagrams of typical a.c. "Keepalite" circuits.

B = battery. C = automatic change-over contactor. L = emergency or secondary lights. M = main supply. T = step-down transformer (if required). T.C. = trickle-charge resistor. Q.C. = quick-charge resistor. R = charging rectifier.

The voltage of the battery on trickle charge in such a circuit is applied to the continuous-load circuit, and the lamps or other apparatus on this circuit must be suitable for the trickle-charge voltage. The continuous load should be constant in current requirements unless automatically-regulated rectifiers are employed to keep the trickle charge constant.

During the period (only after a major discharge) when it is necessary to recharge the battery and at a much increased voltage, possibly 2·75 volts per cell, the battery can be tapped at such a point as to provide a voltage suitable for the continuous-load circuit. As an alternative scheme, the continuous-load circuit can be fed normally from the a.c. system and be switched over to the battery when the a.c. supply is interrupted.

Fig. 6 shows a suitable circuit (British Patent No. 313248) for the above outline scheme and is common to Keepalite, Safetylyte, and Katholite systems. These systems are now so widely employed for various applications that it is not proposed to give very detailed descriptions. It is a matter of choice whether one or two rectifiers be used. The pilot or emergency lighting can be supplied from the battery either through the automatic switch shown in the diagram, or through a separate automatic switch. Essentially in electrical schemes having an emergency battery the system covers the provision of means for charging a battery at a high and at a low rate, and also automatic means for switching the battery into or out of service.

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* C. W. Hughes: *Journal I.E.E.*, 1938, 82, p. 410.

(g) British Standard No. 116—1937, Parts 1 and 2

The Committee which prepared this Specification in 1937 was so constituted as to be representative of many sections of the industry (including the battery makers), as the design of electric power closing devices affects so many interests.

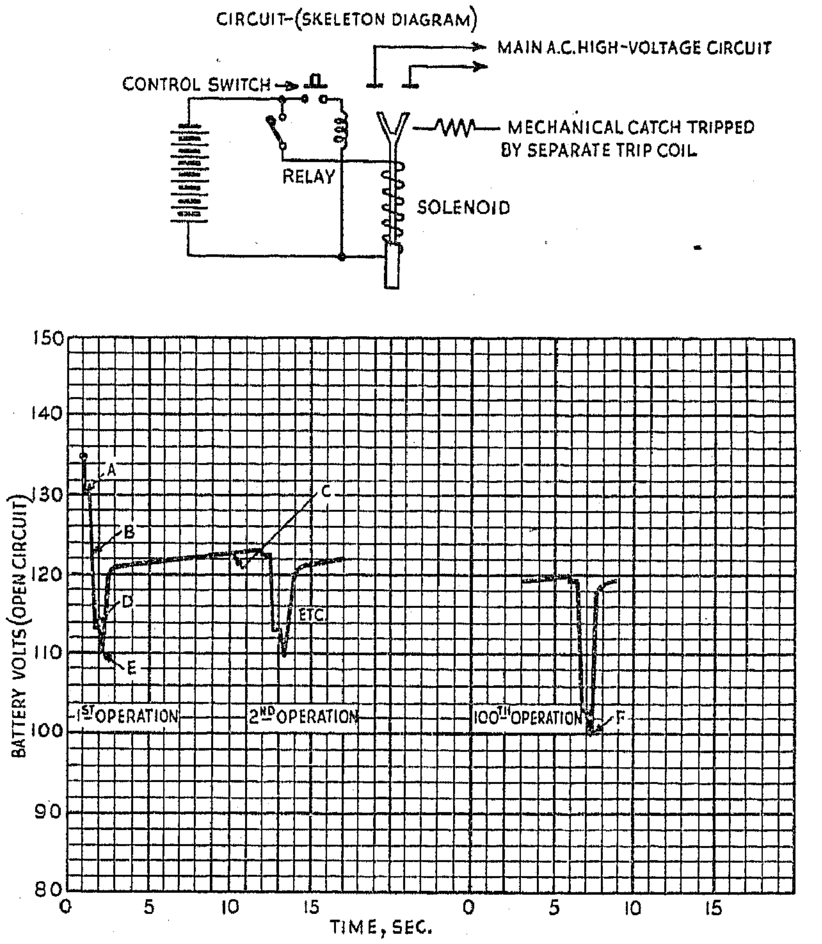

Fig. 7.—Graph prepared from observations during 100 hand-operations of a solenoid switch.

A. Trickle-charge relay energized.
B. Current building-up in solenoid.
C. Part of this period is occupied in waiting for solenoid to drop back when de-energized. Residual magnetism seems to hold it up, the switch contacts then being sustained by the mechanical catch.
D. Solenoid begins to move.
E. Solenoid right home and control switch turned off.
F. This point was a true minimum since, on the 101st test, the control switch was kept "on" until a steady voltage (100 volts) could be read.

Primarily the Specification is for the design of switches and closing solenoids, but it is worded with the knowledge of what is practicable from a battery. The range of operating voltages delivered by the battery is in many cases within much closer limits than that specified, but the wide limits are required to cover those cases where the battery is used for other purposes in addition to switch closing; also to cover the use of several different sizes of switches from the one battery; and to provide a reasonable margin for contingencies.

It is recommended that the battery should be capable in emergency of supplying the continuous load for about 3 hours and still be capable at the end of that period of giving a heavy switching current at a sufficiently high voltage.

Solenoid-operated switches.—Fig. 7 shows graphically the results obtained when closing a solenoid-operated switch 100 times, the solenoid taking 75 amperes at 110 volts from a battery of 60 cells, rated at 120 ampere-hours in 10 hours. The duration of the current depends upon the operator. As the solenoid goes home, the operator releases the controller, and this accounts for the immediate rise to open-circuit voltage; but through slackness on the part of the operator the period can be unnecessarily prolonged. The 100 operations were spread over a period of 20 minutes, and it only took 12 minutes at 2·5 amperes to restore the battery to a full state of charge.

Spring-operated switches.—Manual switching has limitations and some inherent disadvantages. Spring-operated switches with battery-controlled release are finding favour, if only because in attended substations the operator is at a distance from the switch itself when it is being closed.

A battery found suitable for the purpose has a rated output of 20 ampere-hours at 30 volts. This allows ample reserve, as the actual current at 30 volts which is required to operate the release trigger is only about 3 amperes.

Even in unattended substations, these spring-operated switches can be used when normally the switch is in the closed position and may have to be opened only on rare occasions; or vice versa.

The spring-operated switch cannot apparently take the place of the solenoid-operated switch for remote-control work, so long as it is only possible after being wound up to close it once by means of the trigger release, after which it has to be wound up again.

Motor-compressed spring-closing mechanism.—Certain makers have introduced motor-compressed spring-closing mechanism for circuit-breakers, bearing in mind that to conform with a recommendation of B.S. No. 116—1937 oil circuit-breakers dealing with rated symmetrical breaking-capacity currents in excess of 10 000 amperes, or where the 3-phase breaking capacity exceeds 150 kVA, should be arranged for operation from a distance by electrical or other power.

The combined mechanism consists of three main parts —the motor for compressing the closing spring, a worm-and-pinion gearbox transmitting the drive from the motor to the spring-compression mechanism, and the spring mechanism itself. Quite a small motor is sufficient, only ⅝ h.p. on a 250-kVA circuit-breaker, as the motor does not actually close the circuit-breaker.

It is assumed that current from standby lighting batteries can operate the motor, which is of the universal type, especially in the event of failure of the normal supply to the motor. Owing to the light duty of the motors, a much smaller battery can be used as compared with the size required for solenoid-closing.

(h) Fire-Fighting Equipment

In determining the size of new batteries installed in power stations and substations, it may be found advisable to increase their size sufficiently to handle fire-fighting equipment such as the "Mulsifyre" system. This system deals specifically with fires of inflammable liquid, e.g. oil, which is first converted into a non-inflammable emulsion by means of projectors discharging a high-pressure water spray on to the surface of the oil and causing the liquid to emulsify. The fire is extinguished by the non-inflammable emulsion.

The system assumes the availability of an adequate supply of water at a pressure of not less than 40 lb. per sq. in. at the projectors. In some cases a pump or booster pump is necessary, being brought into operation automatically in the event of fire. The pump is driven either by an electric motor of about 50 h.p., by an automatically started steam turbine, or by a self-starting internal-combustion engine. In the case of the latter, a starter battery is required. It seems desirable that the supply to the motor should come from some emergency source rather than depend on the a.c. supply, which itself might be dislocated in the event of a serious fire affecting transformers or high-voltage switches. The emergency battery appears to be the best proposition.

(2) CONTROL OF BATTERIES FOR EMERGENCY LIGHTING AND POWER

Fundamentally, a storage battery constitutes a reservoir, and some of the problems which concern engineers are how to utilize the reservoir to the best advantage, how to maintain it in a full condition ready for emergency, and how to refill it if emptied. It is not proposed to describe in detail the various methods—mains through rheostats, motor-generator, rectifier (dry metal or valve), etc.—by which a standby battery can be charged, nor is it proposed to discuss the relative merits of the various systems.

Any kind of storage battery can be relied upon to give a discharge in an emergency if held in a full state of charge between emergencies. Special types have been evolved to hold their charge for a prolonged period without intermittent charging, but there can be no assurance that such a battery will yield its full rated output without a charge just when required. The problem is complicated by the fact that the same method of control is not suitable for Faure-type batteries and Planté batteries. Trickle charging is not altogether satisfactory over very prolonged periods for a Faure battery. Planté batteries, on the other hand, can be maintained in a fully charged condition throughout unlimited periods between emergencies if some method is employed to compensate for the open-circuit losses.

Three methods are available: trickle charging, floating, and floating/trickle charge.

(a) Trickle Charging

The battery forms part of a special charging circuit by means of which the battery receives a trickle charge more or less continuously. When the emergency arises, the battery is switched over to a discharge circuit either manually or automatically. Experience has shown that a predetermined rate of trickle charge is more satisfactory than to assume a predetermined voltage per cell, as this may be anything between 2·15 and 2·4 volts. There is, of course, a relation between the volts applied and the resulting current, but the counter e.m.f. of the battery varies with temperature, degree of polarization, and extent of sulphation of the electrodes. The extent to which the trickle-charge rate is affected by temperature is indicated in Fig. 8.

If the trickle charge be adequate, the battery will remain healthy indefinitely, and periodical artificial discharges and recharges, or periodical equalizing charges, are unnecessary. If through incorrect adjustment the trickle charge is inadequate, the battery will slowly become sluggish and may require artificial work to restore it to a healthy condition.

A satisfactory conventional rate of trickle charge for batteries up to 100 ampere-hours' capacity is 1 milliampere per ampere-hour capacity at the 10-hour rate; above 100 ampere-hours the convention is 70 mA + (0·3 mA per ampere-hour capacity at the 10-hour rate).

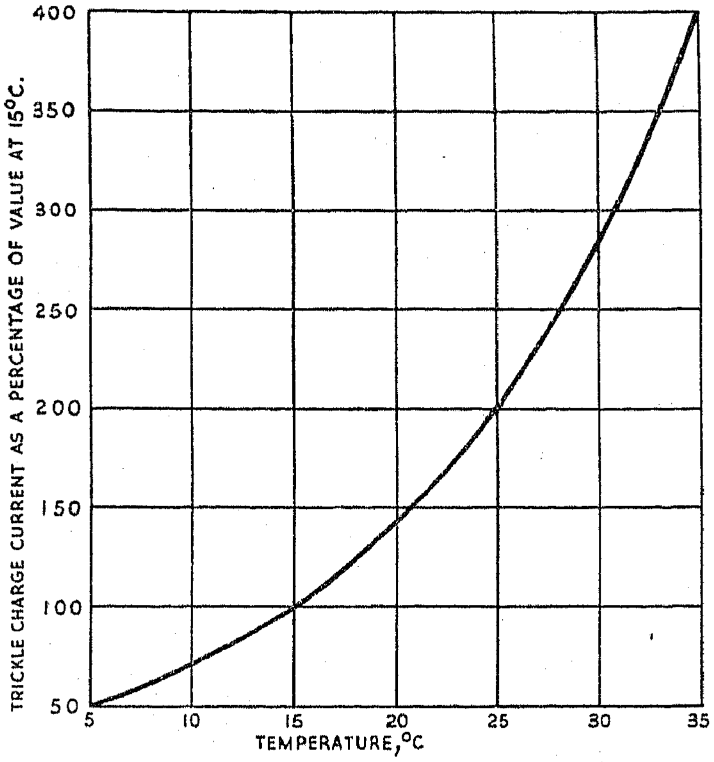

Fig. 8.—Curve showing the percentage variation in the required rate of trickle charge with temperature of the electrolyte, for Planté batteries.

(b) Floating

The battery floats across the discharge circuit which it has to feed in an emergency, the voltage being adjusted to a value at which the battery is barely discharging or charging, say 2·05–2·15 volts. Floating is quite distinct from trickle-charging. There is also a fine distinction between a floating battery and a balancing battery. Under modern conditions it is assumed that the floating battery is normally neither charging nor discharging, whereas a balancing battery may receive slight charges alternately with the giving of slight discharges. It is possible to hold a floating battery in good order without artificial discharges, and to be sure that it is capable at all times of giving its rated capacity, but a balancing battery cannot be depended on to such an extent.

If a floating battery is held to a predetermined fixed voltage, frequently checked and adjusted if necessary, periodical artificial discharges and recharges will not be necessary, but it is advisable to give an equalizing charge at intervals, say once a month. This method is favoured in the U.S.A., meticulous attention being paid to the adjustment of the voltage at 2·15 volts per cell.

If a floating or balancing battery is used intermittently to an extent exceeding, say, 10 % of its capacity, it will be necessary to raise it periodically to a full state of charge.

Several schemes have been evolved to enable a battery to be floated satisfactorily across a main supply varying by ± 6 % without causing the charge current to go permanently outside the prescribed desirable range. This refers particularly to the emergency lighting of cinemas. Variations in load and in the voltage of the supply mains cause very large changes in the trickle charge received by the battery, unless special means are provided. The introduction of ballast resistance in the battery circuit has the serious objection that an undesirable drop of voltage on the load occurs when the battery takes over during a temporary break in the main supply. What is perhaps the most successful of the circuits (British Patent No. 377671) devised to overcome this difficulty, is shown diagrammatically in Fig. 9.

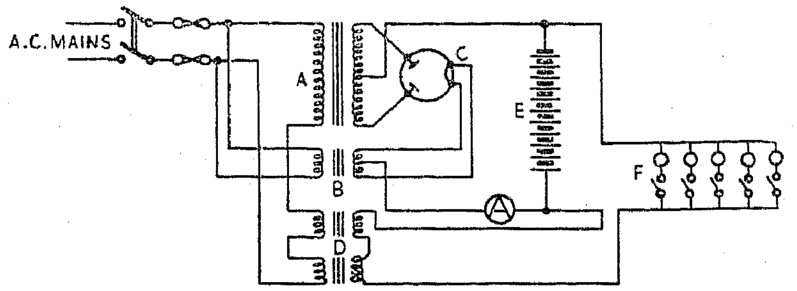

Fig. 9.—Simplified diagram of connections for floating-battery rectifier circuit (British Patent No. 377671).

A = main transformer. B = filament transformer. C = full-wave valve. D = control chokes. E = storage battery. F = cinema safety lights.

Theoretically, by means of the special double-wound control choke D, the voltage applied to the transformer primary winding A will be made to vary with the lighting load, thus tending to counteract the varying voltage-drop in the circuit which otherwise would take place. The floating voltage is not under the control of the operator but is correctly set by the designer, and adjustment made during the manufacturers' works test. If the safety lighting load is reduced or the main voltage rises, the current flowing into the battery will fall to zero at a value corresponding to about 2·2 volts per cell, and above this value the lighting voltage cannot rise. The voltage across the safety lighting load circuit is approximately constant irrespective of the value of the safety load, if this is within reasonable limits.

(c) Floating/Trickle-Charge Batteries

A floating/trickle-charge battery is directly connected at all times to the circuit which it has to serve in emergency, and is receiving trickle charge from a rectifier or other charging source which is simultaneously supplying some external load in parallel.

Such batteries are also known as semi-floating batteries and are of particular use in switch-tripping operations, especially where the feed to the trip along the high-voltage switchboard is common with the feed to the indicating lamps, and where the indicating lamps are used to indicate continuity of the trip circuit; and also where there is apparatus (such as relays) which cannot work equally well on alternating current and direct current.

A typical arrangement is indicated in Fig. 10. Normally one rectifier supplies current simultaneously to the indicating lamps and to the battery at trickle-charge rates, its voltage for the purpose being held at 2·2 to 2·3 volts per cell. The lamp voltage is arranged to suit. A separate rectifier is preferable to recharge the battery after emergency discharges of more than 10 % of the rated capacity of the battery.

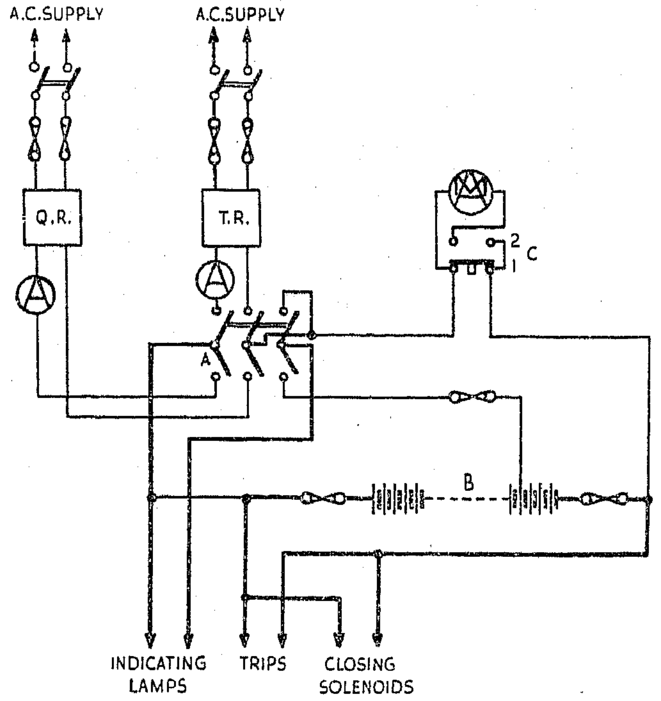

Fig. 10.—Switch-operating battery on floating/trickle charge principle.

A = 3-pole double-throw switch. B = battery. T.R. = trickle-charge rectifier. Q.R. = quick-charge rectifier. C = push switch, spring-closed to Position 1.

(d) Battery and Engine-driven Generator Combination

In those cases where it is desired to make provision for a longer emergency period than that usually given by emergency lighting batteries, a combination of engine-driven generator and battery may be used; a typical circuit is shown in Fig. 11. In the event of a failure of the main supply, the battery instantly takes over the emergency lighting load, and if the supply interruption exceeds some agreed period the engine is started up and a selected portion of the lighting is transferred to it.

(3) EMERGENCY LIGHTING AND POWER BATTERIES ON CONSUMERS' PREMISES

(a) General

Emergency lighting and power appear to become essentials under specific conditions.

As an example, one can imagine an outbreak of fire in a large store thronged with people. Ascending and descending lifts might become immovably fixed between floors if the supply to the motors were to be cut off. In view of the complicated gear associated with modern

Plate

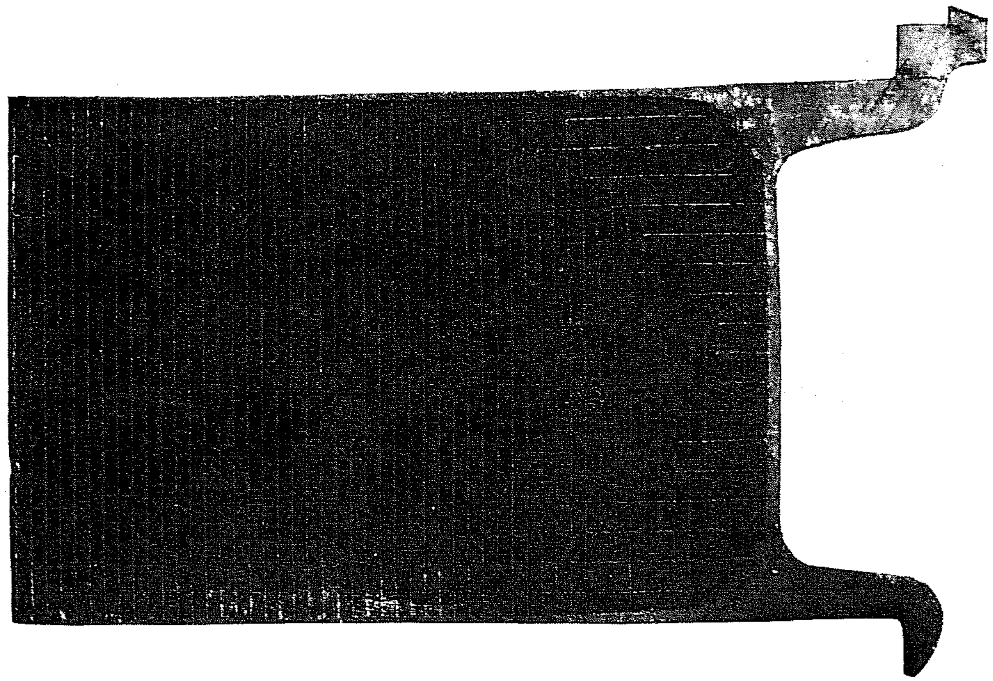

Fig. 2.—Positive plate (Bankside) after 12 years' service on trickle charge.

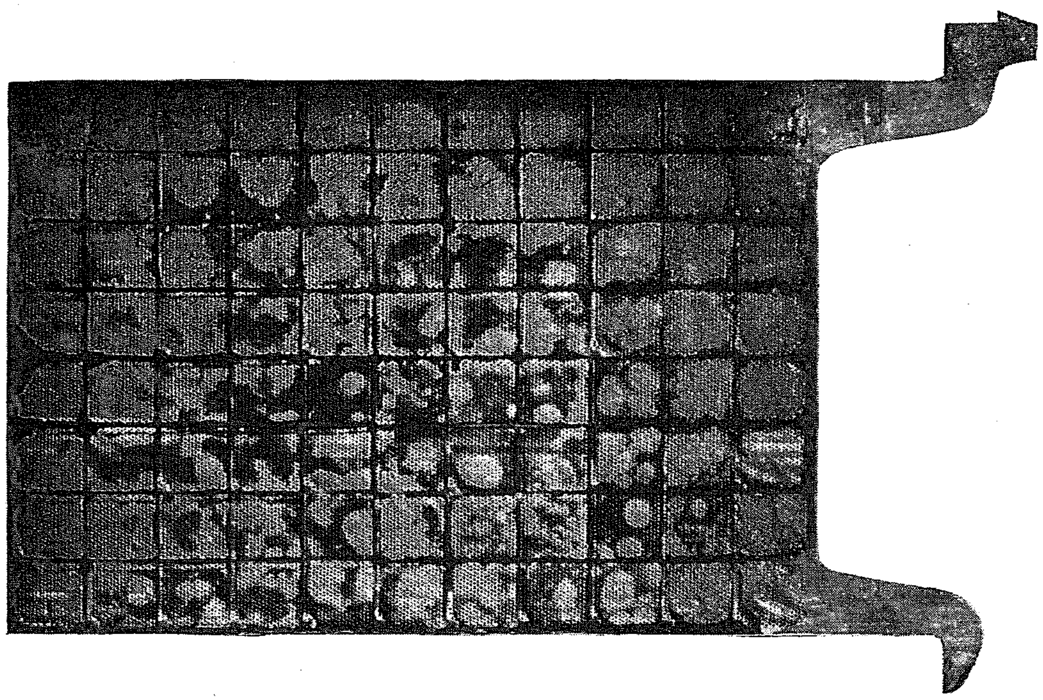

Fig. 3.—Negative plate (Bankside) after 12 years' service on trickle charge.

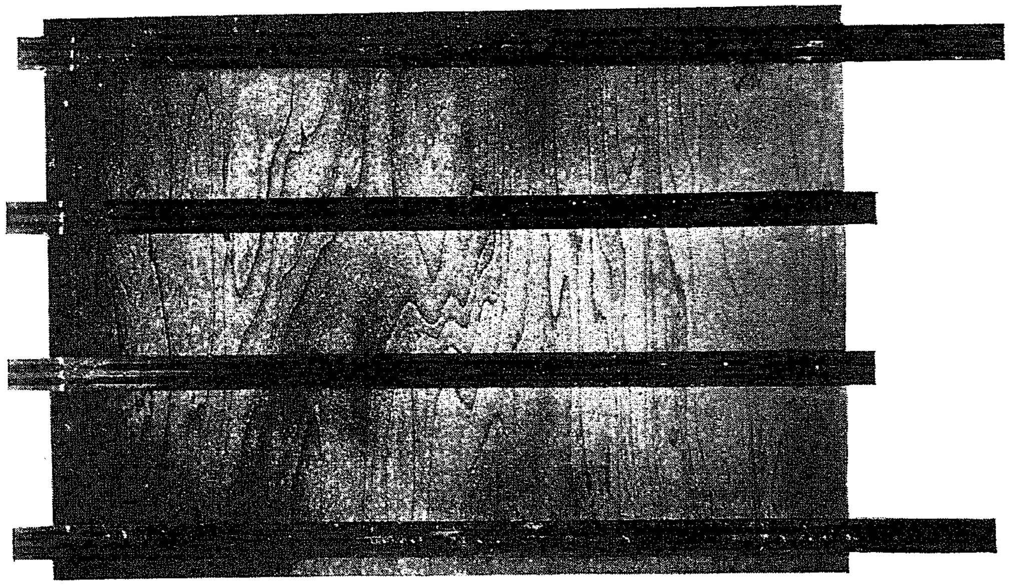

Fig. 4.—Wood separator (Bankside) after 12 years' service on trickle charge.

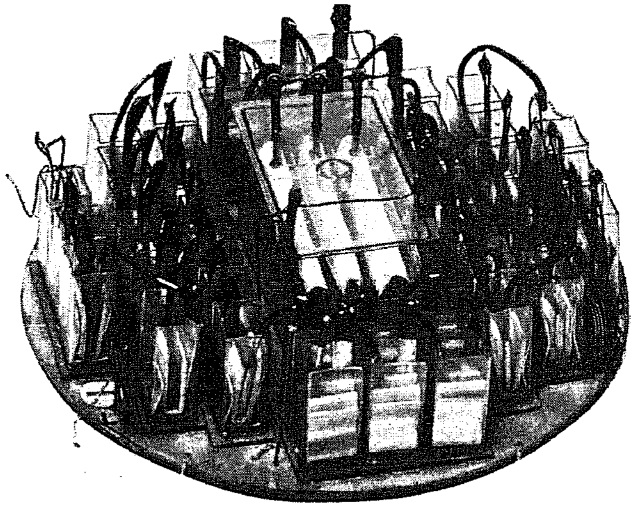

Fig 13.—Miniature batteries (combined H.T. and L.T. on base $5\frac{1}{2}$ in. diam.) for meteorological balloons.

(*Facing page* 232.)

lifts, the supply of emergency power is not an easy problem for such cases, but it is not an insuperable one.

At present, emergency lighting is only compulsory in cinemas, but there is some legal basis for the licensing authorities' requirements for theatres and music halls. It is not unreasonable to forecast that this form of protection will eventually be extended to any buildings in which a great number of people congregate for reasons either of business or of pleasure.

Architects and contractors could simplify the subsequent installation of an emergency scheme in important new buildings by providing part of the main illumination wired in such a manner that there would be no difficulty at a later stage in picking up a circuit at some central point. Such wiring would serve the lighting points normally in use, and would only be additional to an ordinary scheme to the extent that from some central point the circuit would be separate from that (or those) supplying the bulk of the lighting.

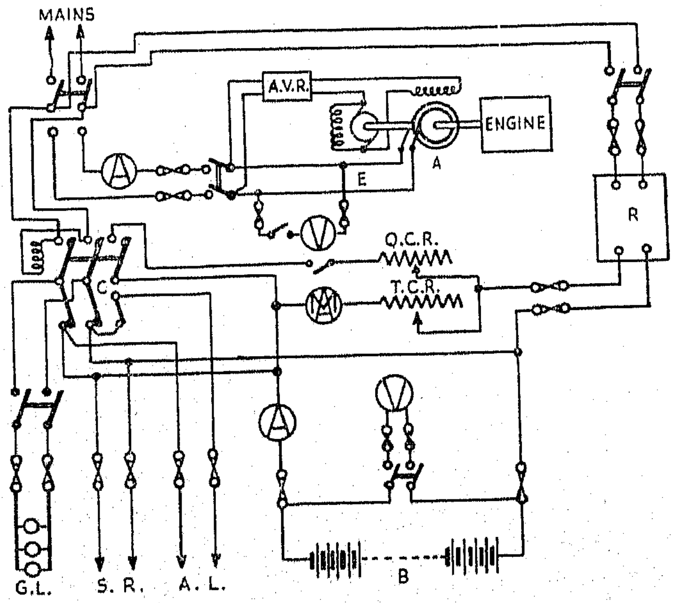

Fig 11.—Typical "Keepalite" circuit incorporating engine-driven alternator.

A.L. = alarm. A.V.R. = automatic voltage regulator, etc. B = battery. C = change-over contactor. E = exciter. G.L. = general lighting. Q.C.R. = quick-change resistor. R = rectifier. S.R. = switch-relay circuit for operating-theatres. T.C.R. = trickle-charge resistance.

(b) Cinemas

The generally accepted form of the secondary lighting required in cinemas by the Home Office Regulations under the powers given by the Cinematograph Act of 1909 is that obtained from a storage battery.

(c) Hospitals

The number of hospitals in Great Britain (excluding mental hospitals, homes of rest, and homes for incurables) is stated to be about 1 300. Of this number, less than 30 % are at present equipped with emergency lighting sets. The number of nursing homes is not known, but of the 3 400 or so appearing in the directory less than 2 % have emergency lighting equipments. Of the emergency sets mentioned, some are for general emergency lighting, whereas others serve the operating theatres only.

In the case of hospital emergency plant, the secondary load usually includes special operating-table lamps. Fig. 12 is a typical diagram of a hospital emergency lighting circuit showing the combined switch-relay which acts automatically and independently of the main emergency system to guard against lamp failure as well as mains failure.

Within the L.C.C. area, emergency lighting is one of the questions ruling the licensing of surgical nursing homes, but even in this case it is only necessary to apply emergency lighting to the operating theatre. Elsewhere these hospitals and nursing homes are under no statutory obligation to install emergency lighting equipment, a situation which would appear likely to receive legislative attention in the course of time.

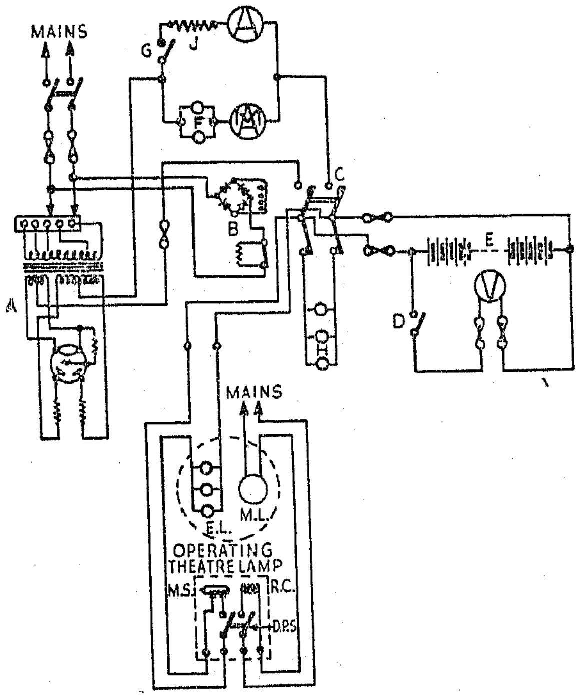

Fig. 12.—Diagram showing use of combined switch and relay in operating-theatre in conjunction with central automatic system.

A = rectifier. B = contactor-coil rectifier. C = change-over contactor. D = voltmeter switch. E = battery. F = lamps for trickle-charge. G = quick-charge switch. H = general emergency lights. J = quick-charge resistance. M.L. = main lamp. E.L. = emergency lamps. M.S. = mercury switch. R.C. = relay coil. D.P.S. = double-pole switch.

(d) Banks

The head office of the Westminster Bank, Ltd., Lothbury, London, is selected as a typical example of a bank depending on electricity throughout a 24-hour day for the carrying-out of most of its major operations. Electrically-driven calculating machines, which cannot be driven by hand, deal with clients' accounts and all necessary records. There is the lighting of the basement, strong rooms on three floors, the operation of lifts for transport of documents and bullion, and the electric drive for heating plant, fire pumps, and sump pumps. A failure of the electric supply for only a short time would cause a serious stoppage of the electrical equipment of the bank, and the result would be particularly acute during a period of 2–3 minutes just before closing time.

To safeguard against the possibility of breakdown, the bank was coupled up to two separate supply companies' systems, but it was found that when a failure of a major character occurred the whole of the supply from both companies was shut down, as both took supply from the grid. It was therefore decided to employ a storage battery to maintain the essential supplies during an emergency, and the following standby equipment was fitted: Two 6-cylinder diesel sets, 50 kW each; one battery balancer and booster; one automatic switchboard; one 200-cell battery, capacity 432 ampere-hours in 10 hours.

This equipment gives immediate automatic change-over for lighting and power purposes, and for machine accountancy. Further, in the event of an extreme emergency, it is designed to light the building efficiently, clear any lifts, run one lift for clearing all floors, maintain the heating plant, run the fire pump if necessary, obtain a water supply, run the sump pump, and operate entrance gates.

If the voltage rises or falls by more than 15 %, the load is then switched over to the battery supply. This is important, as the calculating machines will overheat; in fact, there is a possibility of the coils catching fire through excess voltage, and the machines will not calculate correctly on low voltage.

Against the first cost of the equipment must be offset the saving it effects in that there are no large charges to pay to another supply company for providing standby facilities.

(4) A.R.P. BATTERIES

It would be futile to suggest that the solution to all A.R.P. lighting problems is to install batteries; but these give a simple, safe, and sound form of lighting in air-raid shelters, within the limits of the ampere-hour capacity of the particular battery. It is that limitation which makes it necessary to cater for the recharging of the batteries from generating units preferably independent of the main supply.

A constant-current demand is best met by the installation of standby generating plant, using batteries as reserve standby even if only to tide over the period between the shutdown of the main supply and the starting-up of the standby generating plant.

The illumination of air-raid shelters (holding capacity 50 persons each) would be simplified if various components could be standardized, e.g. lamps of an agreed candle-power or wattage at, say, 12 or 24 volts. There is the choice of alkaline or lead-acid accumulators. Standard car batteries can always be used as an emergency resource. Primary batteries are suitable for torches and handlamps, but have a limited shelf life, and it might be found necessary to renew them on the eve of a crisis if more than, say, 12 months had elapsed since the previous one.

Alkaline accumulators can be kept in a charged condition for long periods. Lead-acid accumulators of standard type, when once charged, require recharging periodically even if not used, but special types are available which allow the period between charges to be at least 12 months.

Alkaline-battery makers claim that if their products are first fully charged and the electrolyte contents are then poured off and the cells hermetically sealed, some discharge (50 % of the rated output after 18 months' storage) can be obtained merely by filling the cells with electrolyte.

Lead-acid accumulators can also be supplied in a dry-charged condition in specially sealed containers in readiness for an emergency of such short notice that time does not allow for any preliminary charging at the outset. Immediately the cells are filled with sulphuric acid, the lead-acid battery will give a large proportion of its rated capacity, even after 2 or 3 years' storage.

(5) BATTERIES FOR COMMUNICATION

(a) Post Office Telephones

The Post Office Telephone Department is by far the largest user of storage batteries in this country, even though changes in policy in recent years have led to a reduction in the average battery capacity per exchange. These changes were outlined by Mr. H. C. Jones in a paper read before the Institution of Post Office Electrical Engineers in 1934.* In general, that paper represents present-day practice, except that the proposed double-battery scheme was not developed. Mr. Jones stressed the importance of continuity of service, and stated that in view of experience with public electricity supplies—of which he gave full details—the Post Office considers some form of reserve to be essential. This reserve might be in the form of (i) prime movers, (ii) secondary cells, or (iii) prime movers and secondary cells. The necessity for the continued use of secondary cells was accepted, the method of working the cells varying with different classes of exchanges.

Changes in Post Office policy and practice since 1928 have been numerous and progressive. The method of building up elements by bolting unit groups together was abandoned in 1934, for various reasons, including the unwieldy weight of a group, the difficulty of lining up the units, and the fact that the plastic flow of lead at bolted joints was considered a potential source of faults. The use of oil films was abandoned in 1934, as experience showed that the negatives became permeated with oil, with loss of capacity and reduction of life.

The Post Office still places great reliance on specific-gravity readings, and controls charge-discharge working by this means. It is found convenient, however, to use ampere-hour meter control for parallel battery-float working. Very low charging rates tend to the stratification of the acid in the electrolyte, which would of course give misleading specific-gravity readings.

(b) Beam Wireless Service

In connection with beam wireless service, storage batteries serve the following purposes:—

(i) For filament supply for the smaller power transmitting valves and for general station lighting at the transmitting station, the apparatus associated with the batteries being constant-frequency valve equipments and master oscillators. The storage battery supplying the filament energy is of generous ampere-hour capacity in relation to the load taken from it. Before being discharged to the filament, the voltage is first stabilized so that the voltage drop over the working part of the discharge curve is maintained within 0·5 volt of 16 volts nominal.

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* Institution of Post Office Electrical Engineers, Professional Paper No. 156.

(ii) For supplying filament and H.T. anode energy for the commercial wireless receivers, and also for general station lighting at the receiving station, the associated apparatus including short-wave commercial telegraph receivers, high-speed land-line signalling, and subsidiary services operated by electromagnetic relays.

(c) Balloon Batteries.

Reference may be made here to batteries designed specially for meteorological recording. Minimum weight and size being all-important, combined L.T. and H.T. batteries, similar to that shown in Fig. 13 (see Plate), which have been put into service weigh 1 lb. and occupy 9 cu. in. They have an electrical output of 16 milliamperes at 106 mean volts for 130 minutes (H.T.) and 0·43 amp. at 2·3 mean volts for 130 minutes (L.T.).

(d) Batteries for Domestic Radio

Radio-battery development has followed the diverging requirements of stationary and portable equipments, the latter category in some cases demanding complete unspillability. As a result, there is a comprehensive design of so-called mass-type batteries for prolonged periods between charges, jelly-acid electrolyte cells for unspillable purposes, and a variety of intermediate designs.

(6) MARINE APPLICATIONS

(a) Electrically-Propelled Ferries

Numerous accounts appeared in the Press during 1936 of the then new Cowes Diesel-electric ferry, a chain-driven ferry or floating bridge between East and West Cowes across the River Medina, Isle of Wight. A brief description of the ferry was also given by Mr. W. S. Lonsdale in his Chairman's Address to the Hampshire Sub-Centre in October, 1938.*

In this scheme, the storage battery plays an all-important part. Sixty traction-type cells, having a rated capacity of 226 ampere-hours in 5 hours, are connected directly across the main generator terminals so that they discharge to assist the generator while the ferry is actually being propelled, and for the rest of the time take a compensating charge current from the specially designed generator. The size of the battery is not determined by the discharge load but by the time available for recharging. If the battery is so small that it will only carry the discharge load when in a fully charged condition, then it will not be capable of absorbing the charge required to keep it in a fully charged condition during the limited charging period available. Further, under such conditions heavy gassing would take place on each recharge, with resultant heavy wear and tear and excessive temperature. Consequently on the Cowes Diesel-electric ferry a battery has been installed which is large enough to carry the discharge load quite easily when in a 25 % discharged condition, and it can absorb the comparatively high charging current required to balance the discharge output without any gassing or overheating taking place. The battery is consequently working at an unusually high efficiency. It receives a thorough equalizing charge once a fortnight as an assurance that it is held in a permanently healthy state.

The special generator characteristics result in the peak load during propulsion periods being carried by the battery without the generator being loaded above its normal rating. Further, the charging current taken adjusts itself automatically to the needs of the battery so that the latter is always maintained in a 25 % discharged condition under varying conditions of loading. According to calculations, the generator output at 105 volts should be 143 amperes, or 15 kW, the full-load rating of the generator. 105 volts corresponds to a battery voltage of 1·75 volts per cell, at which figure the battery should discharge at 400 amperes when in a 25 % discharged condition. Similarly, at 110 volts the generator should give 136 amperes, again equal to 15 kW. 110 volts corresponds to 1·83 volts per cell, at which value the battery should give a discharge current of about 300 amperes. Finally, at 135 volts the generator should give 41 amperes. 135 volts corresponds to 2·25 volts per cell, at which value it is estimated the battery would absorb a current of 41 amperes. This is calculated to be the average amount required to balance the discharge, allowing for a 3½-minute charging period and assuming the cells to be in a 25 % discharged condition.

The accuracy of the above calculation has been very well borne out in practice. Table 4 represents readings observed on an average trip of 80 sec. duration (the power being actually on for 40 sec. of this period), followed by a rest period of 2¾ min., giving a total charging time of 3 min. 25 sec. The length of the trip may vary between 65 and 95 sec., depending upon the state of the tide and the current. The duration of the rest period may vary from 2½ to 3 min., over 200 trips being made in an 18-hour day.

The battery output during an average trip, calculated from the figures in the Table, is about 8 350 ampere-sec., or 2·32 ampere-hours, giving a total daily output from the battery of about 500 ampere-hours, or more than twice the rated output of the battery. If required, the battery would be capable of giving a maximum of 15 trips per hour for 24 hours, corresponding to a total output of 835 ampere-hours, or 3·7 times the rated capacity.

Working under the conditions described, no gassing on charge is observed in ordinary service, but it is found practicable to bring the battery to a fully charged condition by the fortnightly equalizing charges given during the night while the ferry is out of commission. In order to bring the battery down to its normal working point—25 % discharged—the battery is allowed to run the ferry by itself, with the generator shut down for the first 8 or 12 trips after an equalizing charge.

Although it might appear on common standards that the battery is being grossly overworked, this is refuted by the fact that the temperature-rise is not more than 5 to 10 deg. F. during the day, and there is an absence of gas. Also, the following statement in Mr. Lonsdale's Address* implies that the battery is being heavily overcharged. He states: " The readings taken during a normal run when carrying passengers corresponds to a discharge output of about 8 000 ampere-sec. and an input (including 'idling' time) of 13 000 ampere-sec." The latter figure, as shown in Table 4, is the total consumption, of which the battery input is only 8 725 ampere-sec.

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* *Journal I.E.E.*, 1939, **84**, p. 70.

* *Loc. cit.*

Table 4

Cowes Diesel-Electric Ferry: Typical Readings obtained on an average trip of about 70 sec. duration

	Time (sec.)	Battery and generator volts	Battery amperes	Generator amperes	Motor amperes
Start	0	110	300 discharge	140	440
	5	110	300 discharge	140	440
	10	113	220 discharge	130	350
	15	108	300 discharge	140	440
	20	108	300 discharge	140	440
	25	115	200 discharge	130	330
	30	116	120 discharge	120	240
	35	118	80 discharge	110	190
	40	125	0	80	80
Coast	45	132	60 charge	60	0
	50	132	60 charge	60	0
	55	132	60 charge	60	0
	60	133	55 charge	55	0
	65	133	55 charge	55	0
Stop	70	133	55 charge	55	0
	100	134	50 charge	50	0
	125	134	45 charge	45	0
	150	135	40 charge	40	0
	175	135	35 charge	35	0
	200	135	35 charge	35	0
	225	135	35 charge	35	0
Start	250	136	30 charge	30	0

Battery output, 8 350 ampere-sec. Total consumption, 13 650 ampere-sec.
Battery input, 8 725 ampere-sec.
Approximate working efficiency (ampere-hour), 96 %.
Approximate working efficiency (watt-hour), 80 %.

(b) Gyro-Compass Equipment

The Sperry gyro-compass equipment of ships in the naval and mercantile-marine services sometimes includes a battery of 32 cells for the purpose of acting as a stand-by in case of temporary failure of the ship's supply, to keep the gyro-compass equipment functioning, and for the purpose of operating an alarm which indicates the failure or the reinstatement of the ship's supply.

(c) General

Passing reference may be made to the numerous uses of batteries in small ships and their importance in emergency work in large ships, especially in connection with steering gear.

(7) MINING APPLICATIONS

(a) Gaseous Mines

Severe restrictions are placed upon the use of storage batteries in gaseous mines unless there is complete assurance that no spark can be transmitted to the gases which may possibly be present. Thus, although miners' electric lamps (cap or hand type) are in general use, storage batteries are not permitted in connection with battery call systems (bells and signals). In these the voltage is limited to a maximum permissible of 25 volts, fed by Leclanché cells.

A mixture of methane (firedamp) is explosive within the limits of 5·6 % and 14·8 %. The presence of quantities even larger than the upper limit has no narcotic effect. The detection of explosive gases is therefore all-important, as their presence is not easily shown; so much so, that a draft order has been issued by the Ministry of Mines making it compulsory that one competent workman in every eight at the long wall face, and one in every four employed in other workings, shall carry an approved automatic gas alarm. Moreover, such an apparatus must be used near every electrical motor at the coal-face in safety-lamp mines.

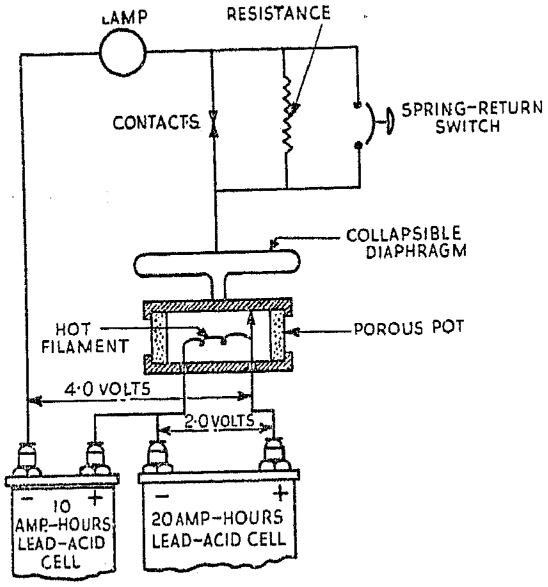

Fig. 14.—The "Ringrose" automatic gas-alarm.

If inflammable gas appears in the porous pot its ignition by the hot filament produces a vacuum proportional to the percentage of gas in the atmosphere. The resulting movement of the diaphragm opens the contacts and causes the lamp to dim.

The flame safety lamp is gradually becoming restricted to use by the deputies and other officials for showing the presence of firedamp, as it has many inherent disadvantages.

Fig. 14 shows diagrammatically the action of an automatic gas alarm applied to a miner's lamp. This device has many claims to superiority over the flame safety lamp, the chief being that it requires no care or skill in its use underground, and operates automatically at any predetermined percentage of gas by causing a dimming of the lights.

Under the latest regulations, which come into force on the 1st January, 1940, the provision of automatic detectors is made compulsory, and apparently the only detector so far approved for meeting Clause 3 of the regulations is that described above.

(b) Non-Gaseous Mines

One of the problems for mining engineers is the best method of firing the fuses attached to the detonators of explosive charges in non-gaseous mines. This applies in particular to the Rand gold mines in South Africa, where reliability is of paramount importance as by law a 24-hour shutdown is compulsory after a misfire.

In one form of electric igniter, a small but intensely hot spark is applied to the firing head of the unit from a 4-volt 10-ampere-hour portable battery. The unit houses an induction coil arranged with a massively constructed high-speed trembler mechanism.

Typical electrical tests on this igniter were as follows: 6 amperes flowing through the primary, trembler operating at 160 vibrations per sec.; battery volts on load, 3·9; volts at coil terminals, 3·5; peak volts (primary), 150; peak volts (secondary) (calc.), 9 150; working spark-gap, $\frac{3}{32}$ in. As regards performance, when firing consecutively 500 3-in. lengths of fuse, 24 to 30 fuses per minute could be fired by one operator. The duration of the spark for each firing was 0·5 sec., and the total energy taken from the battery to fire 500 fuses was about 1/20th of its rated capacity.

(c) Mine Locomotives

For those particularly interested in this branch of electrical engineering, the author recommends a study of papers read before the Association of Mining Electrical Engineers by Dr. Zwanzig and Mr. Muhlhaus.*

Use of battery locomotives underground in this country is permissible, but few have so far been installed.

(d) General

The demand for better and better lighting has led to the standardization of 4-volt lamps in this country. There is also a trend towards the increased use of cap lamps in preference to the usual handlamp design, which was intentionally built to resemble the original Davy lamp.

(8) RAILWAY APPLICATIONS

(a) Train Lighting

Storage batteries are now universally used for train-lighting purposes, although on some high-voltage (1 500 and 3 000 volts) traction systems on the Continent static invertor sets working off the d.c. train-supply provide a low-voltage a.c. supply for lighting purposes, etc. Other modern applications include:—

(b) Kitchen Cars

The London and North Eastern Railway were the pioneers in this country of the use of electric cooking on the kitchen cars of main-line express trains. Electric storage batteries have been employed since 1921 on the system which the Railway has adopted for this purpose.

The latest type of kitchen car is fitted with a 90-cell battery of 210 ampere-hours capacity; the total weight (including trays but not the battery compartment) is 2½ tons. At departure termini and in sidings, external preheating facilities are provided, the actual preheating time being determined by the conditions of the service. The axle-driven generators are sufficient to take the cooking load during the journey and to charge the battery. The cooking load is taken by the battery whilst the dynamos are attaining generating speed and during stops at intermediate stations.

(c) Air-conditioning

This is a modern refinement which has created a demand for bigger electrical equipment, including bigger batteries.

(d) Diesel-electric Locomotives and Passenger Railcars

Many examples could be cited; those in service on the Danish State Railways are selected as an example.

The railcars hold 52 passengers and are propelled at a maximum speed of 120 km. per hour by two 6-cylinder engines, each developing 270 b.h.p. at 1 000 r.p.m. 34 60-ampere-hour cells are installed, working in parallel with an auxiliary dynamo from which they are charged at all three speeds of the diesel engine. Each diesel engine is started by means of a controller which directs current from the battery to the main generator, which then works as a starter motor.

On the main-line railway traffic the number of engines is increased to total 1 100 b.h.p. Two batteries, each of 260 ampere-hours capacity, supply current to the main generators for motoring the diesel engines in addition to lighting the train in conjunction with an auxiliary dynamo.

A typical British specification in connection with batteries required for shunting-locomotives is as follows: To start 6-cylinder, 350-h.p. engine, break-away current 630 amperes, falling in 2 sec. to 250 amperes at firing speed, which may persist for 30 sec. Battery must start engine after standing for 2 days at 0° C.; peak current and time may then be somewhat exceeded, and voltage must not fall below 48 volts on starting peak with battery half charged, nor below 35 volts when fully discharged.

As regards battery locomotives and battery-diesel units, various types are in service, especially in Germany.

(e) General

In connection with signalling, etc., batteries are used for the operation of electric point motors; signal motors; locks on signal and point levers, including the operation of relays associated with and controlling such locks; and train-describing apparatus, block signalling bells, etc. Batteries are also used as central battery for the operation of track circuits, and for the operation of telephone exchanges, telegraphs, and electric clocks, etc.

(9) BATTERIES FOR ELECTRICALLY PROPELLED ROAD VEHICLES

(a) Battery Vehicles

Public attention has repeatedly been drawn to the probability that petrol supplies would have to be drastically rationed in a national emergency.

About half-a-million mechanically propelled commercial goods vehicles are on the road in this country. Of these, probably about 60 % or, say, 300 000, operate only in urban areas. Of these 300 000, not more than 4 000 are battery-propelled, although battery-electric vehicles represent the cheapest form of mechanical road transport, carrying pay-loads at ½d. per ton mile. The old objection that they were too slow has been disposed of—actually under urban delivery conditions they are quicker than petrol-engined vehicles with normally twice the maximum speed of the electric.

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* *Mining Electrical Engineer*, November and December, 1938.

Although expansion in battery-propelled vehicle business in this country has been appreciable in recent years, the rate of development is still very slow compared with that in, say, Germany. There the national policy under the Four-Year Plan of restricting imports, especially if alternative home resources are available, has led to a great increase in the use of battery-propelled vehicles (including barges and locomotives), the power for recharging the battery being obtained from national resources—coal and water—as described in a recent paper by Dr. H. R. Muller, of Berlin.*

In this country, coal and water are available, so the time is almost bound to come when these resources will be utilized to greater advantage than heretofore for a number of purposes, including the specific purpose of recharging the batteries of electric vehicles.

The reliability, high efficiency and durability of modern vehicle batteries are indisputable, and the cost of maintenance compares favourably with that of, say, horse-driven and, for short-radius work, petrol-driven vehicles.

Some attention has been given to the practicability of electricity supply undertakings hiring out batteries for electric vehicles, just as the municipal gas department hire out gas cookers. The scheme has enthusiastic protagonists, but, at the time this paper was written, had not reached fruition.

Different makers have adopted different policies regarding their main design of traction battery, some aiming at robustness and durability as being the two prime essentials for the great bulk of present-day commercial traction work while others concentrate on light traction batteries for a given capacity.

It is an axiom that the compromise between capacity, weight, and space occupied can be varied or modified according to demand, and it is recognized that if maximum capacity is required for a given weight the durability of such a battery must be lowered.

The designer requires to know in advance what is the first criterion—is it performance, or is it life? If the latter, what is the minimum trouble-free period to be assured from one set of plates? The designer can then say what battery performance can be guaranteed. On the other hand, if the first criterion is performance, with specified limited weight and space, then the designer can indicate the life to be expected from such a battery. The two conditions are not compatible. It seems obvious that battery makers will have to continue as heretofore to cater for these two absolutely distinct sets of conditions.

The greatly increased expectation of life of the modern battery over the past 10 years has had an obvious and important effect on the economics of battery-propulsion. It is reflected also in the greater reliability and robustness of the modern battery, which results in reduced maintenance charges and an enhanced ability to withstand extremely arduous conditions and even abuse. The cells can be charged at very high rates, making it possible to replace about 80 % of the rated capacity in a period of, say, 3 hours, if it is considered worth while to put in the heavy charging plant necessary for the charging current required. It is found in practice, however, that in nearly all cases there is actually ample time to carry out charges at more ordinary rates, and under such circumstances the extra trouble and expense involved for specially rapid charging appears quite unjustified.

Occasional trouble with burnt-out motors can be traced to one of three causes: (i) The use of a motor with inadequate margin of safety and with poor efficiency at low speeds. (ii) Over-gearing, especially in hilly districts, resulting in low speeds on hills. (iii) Insufficient battery capacity, especially if the battery be sluggish.

(b) Trolleybuses

The application of storage batteries to trolleybus manoeuvring has developed rapidly during the past 3 years, in view of the interest taken in trolleybuses by municipal transport authorities. For some time alkaline batteries were regarded by numerous authorities, including the London Passenger Transport Board, as the only type likely to prove suitable for trolleybus manoeuvring. Nowadays alkaline and lead-acid batteries find their protagonists apart from the actual makers.

Although the Ministry of Transport has increased the unladen-weight allowance of trolleybuses fitted with batteries for manoeuvring, battery manufacturers are still limited to a weight allowance of 400 lb. (maximum), because transport managers have taken advantage of the extra weight allowed to increase the seating capacity.

It might be considered that this restriction is justified seeing that on tests carried out with one maker's equipment on a Bradford Corporation bus in June, 1937, 30 lead-acid cells totalling 400 lb. (8·45 watt-hours per lb. gross at 5-hour rate) propelled a bus of unladen weight 7 tons 4½ cwt., loaded with 13 cwt. of passengers and battery, a distance of 4¼ miles at an average speed of 4·1 m.p.h., using 48 ampere-hours from a 60-ampere-hour battery.

In tests carried out with another make of bus in October, 1938, a 6-wheel chassis loaded to more than normal unladen weight, running on a good dry non-skid tar-macadam road, only stalled after a distance of 1·1 miles. The recuperative property of the lead-acid battery employed was sufficient to allow the bus to proceed a further 33 % of the distance travelled, after standing for 10 minutes.

Apart from this recuperative property, the lead-acid battery has the advantage that, even when exhausted as regards propulsion ability, it will still have considerable capacity at low discharge rates—sufficient to maintain the statutory lighting for some hours.

(c) Standardization

The standardization of trolleybus batteries is still incomplete. Traction motors supplied by different makers have different characteristics when operating at very low voltages. Manoeuvring-distance and speed are naturally less with 6-wheel vehicles than with the lighter 4-wheel vehicles.

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* *Fordertechnik*, 1938, 31, p. 381.

Actual results suggest that the best compromise in battery voltage is 60 volts for propulsion and 30 volts for lighting, using a series-parallel switch—a method which is giving satisfactory results in practice.

As regards electric-vehicle batteries in general, certain conventions can be found in British practice, but there is no organized standardization. This may be accounted for in part by the different available types with varying characteristics.

In Germany the electric-vehicle manufacturers have accepted standardization to the extent of the number of cells (40 for 3-ton vehicles, 80 for 5-ton vehicles), crate dimensions (20 cells per crate), method of suspension, and position of terminals.

Bus lighting is obtained almost universally from storage batteries. Standardization is at present in suspense as a certain amount of controversy has arisen over the question of series-parallel versus 3-wire battery circuits, and also whether the standard voltage for diesel-engine starting batteries on commercial vehicles shall be 12 volts or 24 volts.

(d) Charge Control

Trolleybus batteries in service are usually charged by means of a constant-voltage generator driven by a motor from the line; or, alternatively, by the traction motor, in which case charging only takes place when the bus is running above cutting-in speed. The battery is not left on charge continuously but at the discretion of the driver. An equalizing charge given once every 3 months helps to wipe out any irregularities.

As regards the charge control of electrically-propelled vehicle batteries, the ideal arrangement from the user's point of view is to plug the battery across a charging supply at the end of the day's run and be certain of finding the battery fully charged the following morning. Several schemes have been evolved to achieve this object, giving the battery an adequate amount of charge, but not far too much, each night.

The two systems most commonly used are (i) the Sangamo ampere-hour meter, (ii) the Poehler time relay. The Poehler system (devised in 1923) or some modification thereof finds favour in at least three countries—Germany, America and Great Britain.

The principle of the control takes advantage of a well-known characteristic of a cell during charging, namely the steep upward rise in the voltage curve at 2·35 to 2·45 volts simultaneously with the evolution of gas at the electrodes. From that point electrical energy is absorbed at an almost constant rate, depending on the size of the battery, until the end of the charge, so that for a given rate of charge the period can be predetermined.

A voltage relay actuated at a preset value corresponding to, say, 2·4 volts per cell, starts a clockwork device set to run for a pre-arranged period, at the end of which the battery charge is automatically cut off by means of a time switch. The switch cannot in itself take into account the factors affecting the shape of the voltage curve on charge, such as rate of charge, and temperature and age of battery, so that adjustment and setting must be a matter of compromise.

An English variation of the original Poehler system includes an electrically-driven timing mechanism. An American charge-control unit based on the Poehler system comprises an inverse temperature-compensated voltage relay, a synchronous-motor time switch, an auxiliary relay, and two signal lamps. The voltage relay opens a contact at about the mid-point of the rapid voltage-rise, or, say, at about 2·4 volts per cell.

In all these automatic charge-controllers the device can only function accurately if associated with a charging rectifier or other plant correctly designed and properly set with its ballast resistances, etc., for the battery to be charged.

(10) BATTERIES FOR VEHICLE STARTING AND LIGHTING

It might appear unnecessary to say much about starter batteries were it not that the types of battery used for passenger-car electrical equipment will prove of great service in many A.R.P. schemes.

(a) Standardization

Standardization has not made much headway in this country, but has reached one important stage in the U.S.A., i.e. the basis upon which battery performance can be directly compared. This is applied in particular to the cranking of diesel engines from cold.

It is assumed that normally only a few seconds are required to start an engine. The current required by the starting motor (universally of the series type) is directly proportionate to the torque required to "break over" the engine, after which—but before firing—the speed attained by the engine is directly proportionate to the counter-electromotive force of the motor. If the engine is in good order, it will fire at between 40 and 75 r.p.m.

With the above premises, the American S.A.E. Standards for establishing the characteristics of a battery performance as to cranking speed and time stipulate that the battery shall discharge at 300 amperes for 5 sec. at 0° F., with a minimum voltage of 1 volt per cell. Below 3 volts (3 cells at 1 volt each) there is no assurance of a spark from the secondary winding of the spark coil.

(b) Voltage Control

Despite the apparently never-ceasing increase in the number of current-consuming devices mounted on a modern passenger car, the motor owner can count on increased trouble-free battery life. The causes are not confined to actual improvements in the design of the modern battery. One of the outstanding changes is represented by the dynamo, which is capable of producing a much higher output over a much larger speed range than hitherto. Voltage control has been a big step forward in maintaining the battery in a healthy state.

The main advantages of the voltage-control system are: (i) The charging current is highest when the battery can best absorb it. (ii) The charging current tapers as the battery approaches a fully charged condition. (iii) Owing to (i) and (ii) the battery is less liable to be exhausted on discharge, or to be overcharged.

A study of the trend of design of 1939 American cars shows that voltage control is being adopted even on the lower-priced cars. It is also noted that in some cases the output of the generator has been increased; this increase has been gradual. It was recently recorded* that during the past few years the load on the dynamo on private cars has increased from 7 amperes to a maximum of 25 amperes.

(c) Initial Starting

Special types of batteries have been evolved for the ground starting of civil aircraft engines, and also for "swinging" the engines of buses at bus depots.

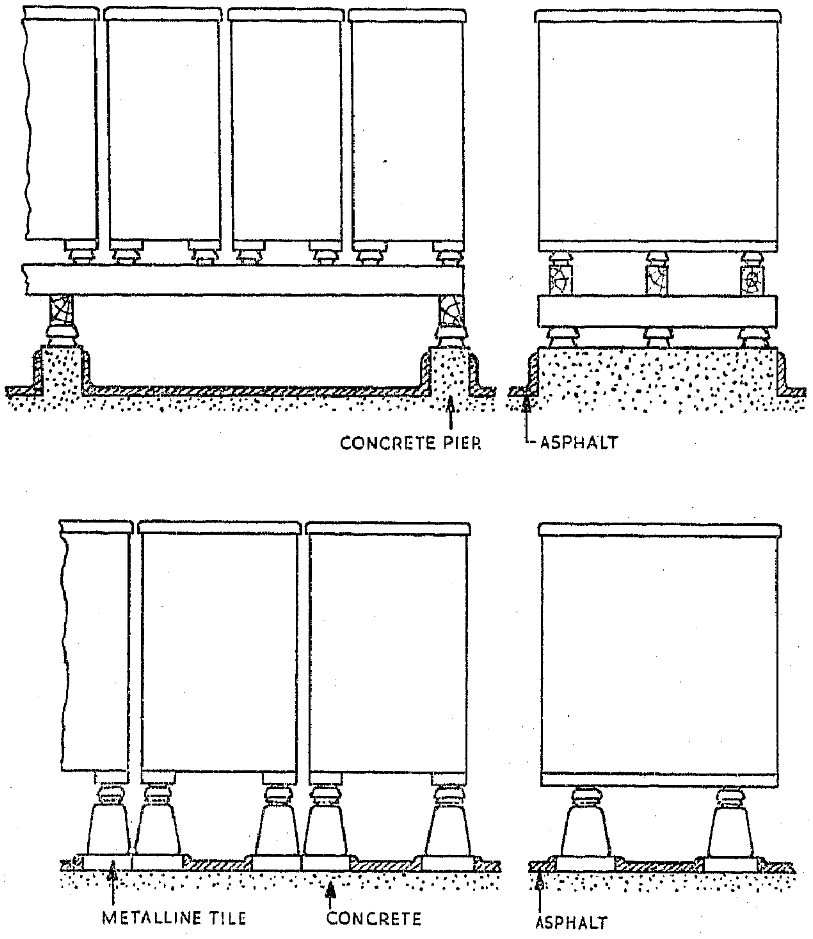

Fig. 15.—Various methods of preparing floor-footings to carry heavy cells.

(11) BATTERY HOUSING

(a) Large Power and Lighting Installations

The chief points connected with these installations concern floorings, protective coatings, heating, and ventilation. It may be deemed essential to consider the placing of the battery in a room invulnerable to bomb attacks, seeing that the primary object of the battery in future for standby work will be to provide light and possibly power when all other electrical sources are temporarily not available. This is not creating a precedent, as the author recalls that the battery room of the Smithfield Market Electric Supply Co. at the end of last century was at least two storeys below ground level.

(b) Flooring

British battery makers are in agreement in recommending tiles set in bitumen, or alternatively an acid-proof grade of hard asphalt, as a satisfactory material with which to surface a battery-room floor; although a concrete floor is quite suitable in many cases, especially if served with one of the acid-proof paints which are available.

In one type of battery-room floor sometimes employed in the United States, sheets of light-weight asphalt-saturated and coated rag felt, with, in addition, a double layer of 50-lb. oiled paper, are inserted between the foundation of the floor (concrete or the like) and the hard-wearing acid-proof mastic surface. The felt and oiled paper act as a slip joint, facilitating repairs to the wearing surface. This method is recommended where another room is directly under the battery room or where any leakage of acid into the building structure or foundations might be a serious matter.

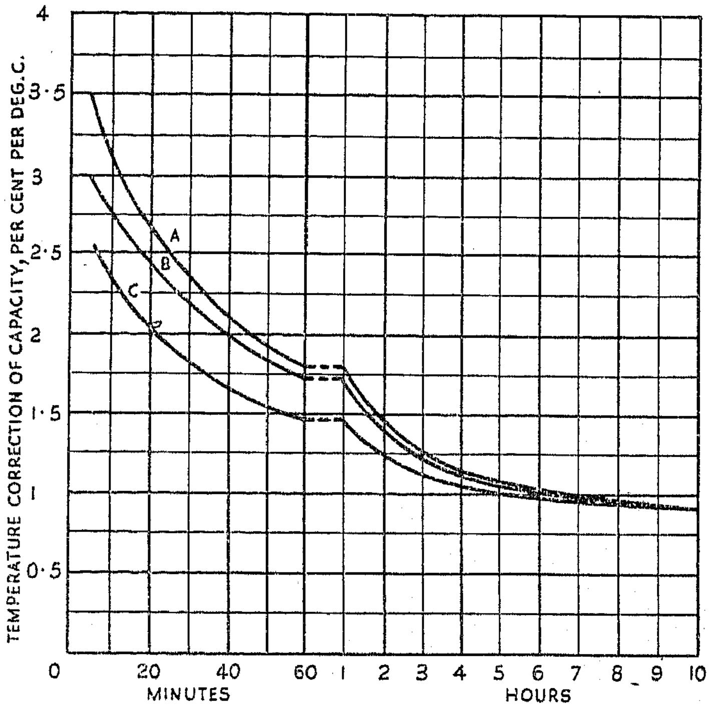

Fig. 16.—Curves showing the approximate percentage variation in capacity with temperature at various rates of discharge for Planté and Faure type batteries.

A. Planté type.
B. Faure type (traction).
C. Faure type (starter).

Fig. 15 shows various methods of preparing floor-footings to carry heavy cells.

(c) Heating

In the past it has not been found necessary to recommend the heating of battery rooms in this country, although it has been regular practice on the Continent. It has always been considered that, as the risk of freezing is infinitesimal, it is not necessary to go to the extra expense. This policy no longer applies. It is not a question of freezing, but the fact that large power and lighting batteries are nowadays required to give their full rated capacity during a cold winter snap.

The curves reproduced in Fig. 16 show the effect of temperature on capacity, and emphasize the importance of maintaining the ambient temperature of the battery at not less than 60° F. during cold spells, especially if the primary object of the battery is to cut down maximum peak demands, in which case the battery has to give its rated capacity at very high rates of discharge.

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* R. M. Critchfield: *Journal of the Society of Automotive Engineers*, 1937, **41**, p. 358.

(d) Ventilation

The usual stipulation that the battery room must be well ventilated is based on the assumption that otherwise there may be an accumulation of gas evolved during charging, sufficient to attain explosive proportions. In actual fact the risk of an explosion is too remote even to be considered a hazard. True, if a light be brought to the vent of an enclosed cell during charge, or very soon afterwards, an explosion is assured, leading to the fracture of the cover and container (if of glass); but in open-type cells, regardless of size, a lighted match can be applied to the largest gas bubble floating on the surface of the electrolyte, and the resulting " pop " will be diminutive compared with that from a toy balloon filled with air, if suddenly punctured.

It is possible to work out the amount of gas necessary to produce explosive proportions in a hermetically sealed chamber, knowing that an inflammable mixture contains 4 % of hydrogen and that the mixture becomes explosive when it contains about 6 % of hydrogen. In practice, however, this formula cannot apply, because a chamber or room containing a battery would never be hermetically sealed, and the rate of diffusion of hydrogen in air is extremely rapid.

(12) MISCELLANEOUS CONSIDERATIONS

(a) Electrolyte

After over 50 years no substitute for sulphuric acid as the electrolyte for lead-acid batteries has been adopted. Battery makers are in complete unanimity in dissociating themselves from the countless " special electrolytes " which have come and gone.

(b) Alloys

The metals used for the electrodes of lead-acid storage batteries are in the main similar to those used for the same purpose 50 years ago; that is to say, a Planté electrode is made of pure lead and the Faure-type electrode consists of oxides of lead applied to a frame of pure lead, or, more commonly, of antimonial lead alloy.

Battery makers agree that antimonial lead is not ideal; but exhaustive tests in quite recent years by various authorities in different countries have produced the universal conclusion that, despite certain disadvantages, no alloy has yet been discovered which gives results superior to, or even the equal of, those given by lead-antimony on a commercial basis.

With this reservation, tellurium-lead and calcium-lead have perhaps shown most promise of the various alternative alloys tried out. In fact, it has been reported that calcium has been substituted for antimony to a certain extent for accumulator plates in Germany, but possibly on the ground of national economy.

(c) Oscillograph Tests

The design of many modern schemes employing storage batteries—e.g. telephone systems, radio beam systems, automatic emergency systems—calls for a prior knowledge of the manner in which the voltage of a cell changes momentarily when the cell is switched over from charging or floating to discharge. The fall in voltage during the first fraction of a second cannot be measured by a voltmeter, nor can it be calculated from the nominal internal resistance of the cell.

The cathode-ray oscillograph is extremely useful in this respect. The cell to be tested is first allowed to stabilize itself on charge at various voltages. It is then switched on instantaneously to discharge on a non-inductive circuit at various rates. An oscillograph record of the voltage of the cell is taken over the period 5 sec. before to 20 sec. after the change-over from charge to discharge.

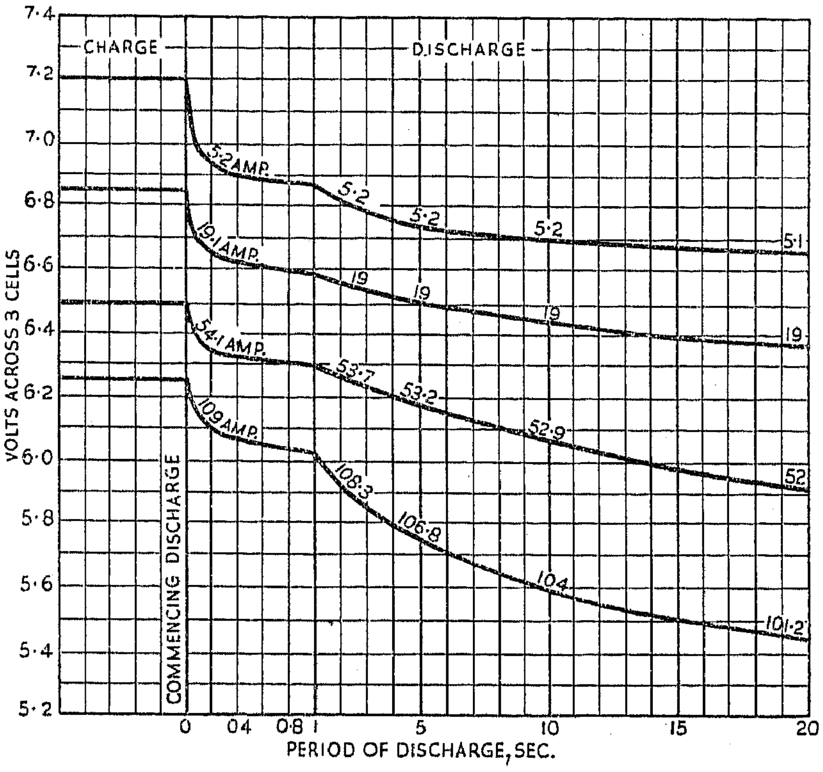

Fig. 17.—Curves showing variation in battery initial voltage on discharge according to value of float voltage.

Fig. 17 is a typical example of the useful results obtained by means of the oscillograph in connection with battery design.

(13) ACKNOWLEDGMENTS

In conclusion, the author desires to thank all those who have helped him in any way in the preparation of the paper, and especially the technical staff of the Chloride Electrical Storage Co., Ltd.

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Manufacturers and contractors, including the Electric Construction Co.; Higgins and Cattle; Frichs (Aarhus); International Gas Detectors; R. A. Lister and Co.; Mather and Platt; Partridge, Wilson and Co.; Siemens and General Electric Railway Signal Co.; Sperry Gyroscope; Switchgear and Cowans; Westinghouse Brake and Signal Co.

APPENDIX

A Review of Correspondence received by the Author from Battery Users and Authorities

Numerous battery users have been asked by the author to state the purposes for which their batteries were installed, and to express an opinion as to the utility of a battery for such purposes. Space precludes reproduction of the replies *in extenso*, but the following is a condensed summary from a large selection.

From the letters there would appear to be a consensus of opinion that batteries are an essential adjunct to the electrical equipment of a large municipal supply system for (*a*) provision of control of oil circuit-breakers on all main switchgear; (*b*) general emergency lighting purposes, including system control rooms and main telephone exchanges; (*c*) switchgear operating; (*d*) operating indicator lamps.

Several users have pointed out that, where d.c.-driven auxiliaries are installed, a battery is of great service in the event of a shutdown and would enable the main supply to be resumed much more quickly than would otherwise be the case; also, that if supplies are bought in bulk, by installing batteries it is possible to effect considerable economies with regard to the charges paid for kilowatt demand.

One engineer considered the battery form of standby the most perfect, and that even in the modern station, where auxiliaries are driven by a.c. motors, batteries are still essential for supplying current for the operation of switchgear and other like utilities.

Others state that by the employment of a large battery economies can be effected, through obviating the necessity of starting-up steam plant for short periods to take peak loads, or, alternatively, enabling converting plant (where used) to be shut down during periods of light load.

The officials of a certain bank regard batteries as a useful and essential adjunct to a large bank under modern conditions; whilst at another bank the view was expressed that, when working with an automatic equipment, the battery is essential for providing emergency lighting in strong rooms, corridors, and staircases, and in addition for operating the air-raid alarm. The only alternative would be a generating set operated by an internal-combustion engine.

From hospitals many interesting accounts were received, a typical one being that of a battery working with an automatic equipment to provide auxiliary lighting for the main operating-theatre lamp. The automatic plant has come into action on at least one occasion, with entirely satisfactory results, and not the slightest inconvenience was caused to the operating surgeon and his staff. Had the auxiliary service not been available, it would have been necessary to use electric torches.

At a large sheet-glass works, batteries costing £2 100 were installed to ensure continuity of supply to the essential drives for about 2 hours in the event of an interruption of the main supply. For each hour of failure of supply the loss incurred would be £1 610. The number of times the batteries had been called upon, to March, 1939, was 30. The total estimated saving was approximately £5 200.

The Gothenburg (Sweden) Municipal Electricity Department are users of several large batteries, and have explained that although they have endeavoured for the past 12 years to check the increase of d.c. load by developing a cheaper tariff for low-voltage a.c. distribution, actually the d.c. load continues to rise, and batteries are therefore used as a standby for the hydro-electric supply, which is usually put out of action by lightning two or three times a year. The load is then divided between batteries and steam plant, including steam accumulators.

The engineer to a large multiple store explained that batteries had been employed to give a supply of emergency light; the alternative being gas, which would have to be lit each day and kept burning during the business period.

Users of batteries for trolleybuses record that the batteries are found to be invaluable for manoeuvring in the depot, at termini, and in emergency conditions; while motor-coach users state that lead-acid batteries are found reliable and efficient for internal-combustion-engine passenger vehicles.

Finally, Col. R. E. B. Crompton has written to the author as follows: "I do not think anything has occurred during the past 10 years which would make me alter my opinion on the desirability of encouraging the use of accumulators for all cases of public supply in villages and hamlets. I still think this is the best means of providing the necessary reserve for continuing the supply of electricity during the hours taken in making repairs to the overhead wires connecting the village with the point at which the electric supply is generated."

[The discussion on this paper will be found on page 243.]

WRITTEN CONTRIBUTIONS TO THE GENERAL DISCUSSION ON THE ABOVE PAPER

Mr. A. D. Constable: Although the author implies that the reduced probability of interruptions of supply assumed to be the result of the completion of the grid scheme has led to the scrapping of standby batteries, does he not himself give another more adequate reason —" even this stupendous figure (of 150 000 000 watt-hours) would be of little avail for public distribution schemes. . . ."? The fact is that the growth of public supply, coupled with the rapid elimination of d.c. distribution, has made the problem of providing battery standby supplies too stupendous. The loss of such highly desirable sources of emergency supply may be deplorable in present conditions, but the state of knowledge of battery construction seems to make it economically inevitable.

The battery as a standby still holds its own for special local applications, as stated by the author, but even in these cases it has its limitations in that, unless of abnormal capacity, it can only maintain the emergency supply for a short time. There would seem to be room for more combinations of small batteries of the starter type, with internal-combustion-engine driven generators where an immediately available alternative supply is a necessity and when it may be required for many hours. Every case must of course be dealt with on its merits and a decision be made as to whether the cost of the standby plant is a reasonable insurance.

It is somewhat remarkable in view of the enormous progress in other directions in electrical engineering that no major developments have been made in the design and construction of lead-acid batteries during the last quarter of a century or longer. Except for minor improvements in detail and the ability to guarantee greater uniformity of performance, such batteries remain in all essentials unchanged. The field of use would extend enormously were it possible by some new discovery to increase largely the capacity/weight-bulk-cost ratio.

A submarine can only maintain its full speed submerged for about an hour with the biggest battery it can carry. Moreover, it must remain on the surface frequently for some hours for recharging. A better form of battery would avoid many of the present limitations of the utility of submarines and would free the commander from much anxiety. An immediate objective which I used to put before the battery makers was twice the capacity on half the weight without loss of durability. It is only possible to meet any two out of these three conditions, and so the makers were reduced to arguing that the batteries were very useful as providing ballast!

A point of much interest raised by the author is the use of batteries for road vehicles. Although the battery is a permanent dead load to be carried, battery-propelled vehicles can undoubtedly show a good case, at any rate for urban delivery services, quite apart from the advantage of their independence of imported fuel. The principal obstacle to the larger use of such vehicles seems to be the necessity for frequent recharging, occupying some hours. It is not convenient or even possible in all cases to fit in these charging periods when the vehicle will be out of use. The remedy for this objection is to set up an organization for the hiring-out of standard batteries, as is suggested by the author. A battery car would then be able to change its run-down battery for a freshly charged one at a few minutes' notice at any garage catering for such service, with little more trouble than is involved in filling up with petrol. A number of standard battery sections could be made to serve for all the types of vehicles normally required. The owner of the vehicle would be relieved of all trouble associated with battery maintenance and would only be required to exercise ordinary care in its use. It is believed that in normal times a properly managed concern of this kind would be successful and that its existence would give an impetus to the extension of the use of battery-propelled vehicles.

There is, however, one drawback which would have to be met on occasions such as the recent unusually cold spell. With temperatures on the road round about 20° F. the capacity of the battery would be very seriously affected—the curves in Fig. 16 show that it might be not much more than half the normal value. It would be of interest to know of users' experiences during the recent cold weather as to how far batteries for various purposes have been able to meet the requirements for which they were installed.

Mr. P. Good: I note the author's frank admission that there is very little standardization of motor-car batteries. That a substantial gain in convenience, and therefore in ultimate cost, would accrue from a greater measure of limitation on types and sizes is hardly likely to be challenged. When the British Standards Institution first gave consideration some 10 years ago to the subject of standardization of batteries an inquiry as to the types and sizes used by the railway companies showed that about 300 different types and sizes were being called for. There may have been improvement since then, and present conditions might provide the best opportunity the industry has ever had of preparing for the future by the elimination of as many unnecessary models as possible.

The fact that the paper was written some time ago presumably accounts for the suggestion in Section (4) that the illumination of air-raid shelters would be simplified if various components could be standardized, e.g. lamps of an agreed candle-power or wattage at, say, 12 or 25 volts. Since the paper was written quite a lot has been done, with the author's assistance, with regard to the standardization of the lighting of air-raid shelters. At the request of the Ministry of Home Security (A.R.P. Department) a Committee of the British Standards Institution was formed, with the result that a Specification for the Lighting of Air-raid Shelters has been published as BS/ARP 6. A voltage of 12 volts has been standardized, and the wattage of the lamps has been standardized at 10 W. The number of lamps, the size of the wiring, and a number of other components are dealt with in the Specification, and several manufacturers have produced complete sets of lighting equipment to comply with it.

A further Specification along somewhat similar lines is BS/ARP 7, which deals with the Lighting of Report and Control Centres. For the normal lighting the supply is taken from the mains at the full mains voltage, while the emergency lighting, which is brought into operation by means of a manually-operated switch when the main supply fails, is provided by an entirely separate wiring system the supply for which is at 24 volts.

More recently still, another Specification for the lighting of shelters has been issued. This is BS/ARP 26, which deals with a reduced scheme for the lighting of shelters where a.c. mains are available. If the lighting is supplied by a battery with a second battery in reserve, as provided for in Part 1 of BS/ARP 6, the cost of the work is about 5s. per person for a 50-person shelter. If, however, the normal lighting is taken from the mains with provision for emergency lighting, the cost in terms of Part 2 or Part 3 of BS/ARP 6 is about 10s. per person accommodated. With a view to providing an installation making use of the mains but still providing for reserve and a reasonable standard of quality at a cost of about 5s. per person, the Specification BS/ARP 26 was evolved. Here again, the voltage is 12 volts and the lamps are rated at 10 W. The transformers are covered by the Specification, and in general I think it is safe to say that the lighting of shelters is now fairly rigidly standardized.

Mr. R. D. Spurr: The introduction and proper application of the trickle charger does not appear to be thoroughly understood, and many users of batteries are still discharging these unnecessarily. My undertaking had two small batteries installed in 1924 for switchgear operation, which were alternately charged and discharged, the bulk of the load on the batteries being, of course, the indicating lamps for the switchgear. In due course both batteries deteriorated and we eventually replated them, but shortly afterwards a trickle charger was installed, sufficiently large to carry the bulk of the indicating-lamp load, leaving only the speeder-motor and rheostat control to be taken by the battery. As there were two batteries and it was not considered wise to bank them, each battery works one week with the trickle charger in parallel and then stands a week; this arrangement has more than doubled the life of the batteries.

New switchgear is about to be installed and the indicating lamps will, as far as possible, be supplied with alternating current at low voltage by means of small transformers, leaving only the switchgear operation and speeder-motor controls to be worked by the battery. Eliminating the indicating-lamp load makes it unnecessary to provide more than one battery, as by trickle charging this can be kept ready for use and in addition to switchgear operation will provide a limited amount of emergency lighting. If any substantial amount of lighting is required I would suggest that two batteries be installed, one for switchgear operation and the other for emergency lighting. I am quite convinced that had trickle charging, as we now know it, been available in 1924 we should not have discarded the battery, which gave approximately 200 amperes for 10 hours.

The introduction of the metallic rectifier has given a further impetus to the use of batteries for road transport. My undertaking has within recent years replaced petrol-driven vans by battery-driven vehicles, which so far have presented very few difficulties in operation. Vehicles requiring to run extra mileage can be given a midday boost, and for this purpose we obtained a metallic-rectifier charging plant capable of giving the high boost necessary.

We have approximately 12 000 assisted-wiring consumers whose installations are maintained and lamps replaced by the undertaking, and five 7-cwt. vans are used for this purpose. On one occasion whilst the electric van was out of commission because of a mechanical defect, the driver had to revert to his petrol-driven van, and although this has a much higher speed he found to his surprise that he could not make as many calls with it as with the electric van in the same time.

The metallic-rectifier charger has also facilitated the use of batteries in that, instead of one battery, a number of batteries, each with its own charging apparatus, can be employed, located exactly where they are wanted; and the small alternating current required for the rectifiers can be carried on very small wires, thus saving a great deal of copper loss in transmitting direct current over long distances.

Drs. R. C. G. Williams and **G. D. Reynolds:** The author says very little about domestic radio batteries. We realize that these form a very small proportion of the total number of accumulators in use, but they are worthy of some consideration because, according to our estimate, there must be at least 3 millions in regular service. Most accumulators on industrial equipment are looked after by skilled or semi-skilled operators, but the radio accumulator reaches the general public, and, even where it is taken to a reputable charging station, it spends most of its time in relatively unskilled hands. These cells will not stand up to nearly the abuse that is suffered by the average motor-car battery. It seems desirable that a " tougher " radio accumulator should be designed that would stand a certain amount of misuse and might be charged at a higher rate without damage.

We feel that the comparative stagnation of radio-accumulator design has had something to do with the development of the all-dry radio receiver, with its attendant difficulties of design to allow for a L.T. source which changes considerably in voltage during use. The accumulator offers a much better source of L.T. supply at constant voltage, but this advantage tends to be offset by its present inconveniences. Of the types at present available, the free-acid cell has proved reasonably satisfactory—apart from the general comment made above. It appears in a great variety of forms and it includes the more foolproof unspillable accumulator that is practically essential for most portable receivers. The jelly-acid cell, although it has a larger capacity than an unspillable free-acid cell of the same dimensions, has not proved very satisfactory on our finding. It will not stand up to maltreatment, tends to lose its capacity because the jelly shrinks away from the plates, and, if not topped-up with care, is liable to become unpleasantly spillable.

Many firms manufacture free-acid cells with the alternative of glass or celluloid containers. Is this necessary? Surely the glass cell has proved more robust, clean and popular, although it is a little more bulky. Perhaps the author could state whether the celluloid cell survives for reasons other than its slightly smaller weight and size.

In general, there is a very large variety of radio accumulators. Would it not be possible to reduce costs and simplify the marketing if some degree of standardization could be arrived at, leading to a smaller number of types?

Recent developments in accumulator design include the dry accumulator, which seems to solve many of the problems of a reliable unspillable cell of compact design. Perhaps this kind of cell may revive the accumulator H.T. supply at a popular price, and so lead to better output stages on battery receivers.

We should welcome from the author information on any other up-to-date developments in accumulator design, especially improvements that may give us a less "messy" and more reliable component.

[The author's reply to this discussion will be found on page 248.]

NORTH-WESTERN CENTRE, AT MANCHESTER, 20TH FEBRUARY, 1940

Mr. W. Fennell: Amongst the various sub-divisions of the paper is one on the use of batteries as a standby. I should point out that from the financial point of view the use of a battery as a standby is a hopeless proposition, if it is likely to be required for more than 1½ hours at a time. The capital charges of a battery standby supply, at the 1½-hour rate, are just about equal to those of a fairly cheap oil-driven plant of equal capacity. The battery can be used at its full kW rating for only 1½ hours, and must be full, when discharge commences, to give even this period of service; whereas the oil-driven plant will run at its kW rating, accidents excepted, for as many hours as required.

The scale on which batteries were used for standby purposes in power stations prior to the coming of the grid was not so great as the author suggests. He speaks of 156 million watt-hours at the 10-hour rate (the capacity removed from central stations during 1923–38) for the whole country as being a stupendous figure. Actually, it amounts to less than 50 000 kW for 3 hours, just about equal to the output of one rather small selected station (of which there are about 160); so that what has been scrapped is a very small portion of the whole.

Batteries have a very definite field of use for peak-lopping purposes. If a peak does not exceed 1½ hours in duration it will actually pay to put in a battery to lop it, but if it persists longer than that the use of batteries must be reserved, from the financial point of view, to those who have retained them from pre-grid days and have to consider only the question of maintenance. Under such conditions it is quite easy to save from £2 to £3 per kW on peak load if the batteries and a sufficient d.c. load have been retained—the grid charge being £3 to £3 10s. My experience of batteries is that for this purpose, i.e. used only 10–20 times a year, the positive plates will last at the very minimum 14 years and the negative about twice as long. One could safely estimate a life of about 20 years for a peak-lopping battery.

I cannot help calling attention to the case of the Westminster Bank, dealt with in Section (3). It would be interesting to know why the Bank should have been advised to spend so much money, including the cost not only of the battery but also of duplicate Diesel sets, merely to provide a standby supply in an office building. The standby provision appears to be completely out of proportion when it is remembered that a few dozen small battery-operated lamps would have saved most of the capital. The same criticism applies to permanent lighting for A.R.P. shelters.

With regard to marine applications, I should have liked to learn something of the wonderful work done by the author's firm on submarine batteries (excluding, of course, those installed in British submarines); and about the method of accumulator rail service, in use between Dublin and Bray, where the battery is given a high-rate boosting charge automatically at each railway station.

Mr. W. Kidd: I suggest that the major causes for the displacement of batteries are the change-over from direct current to alternating current and the substitution of petrol-driven buses for tramcars. There is a wide field for the use of batteries, and I think their use should be encouraged in many cases where 100 % reliability is almost essential, i.e. for pilot lamps, certain vital services, large stores, etc.

It is bad policy to allow places where large numbers of people congregate—such as large stores, railway stations, theatres, etc.—to be in a position such that all lighting would fail immediately the a.c. supply was interrupted. In most cases like this, supply authorities arrange to give alternative sources of supply, but where this is not possible then a battery should be installed. The matter must of course be considered from a commercial point of view.

The development of equipment for converting from direct current to alternating current, if only for small capacities, would encourage the use of batteries. There are many cases where the supply is preferably taken from an a.c. source, but in certain emergencies must be changed-over to direct current. The case I have in mind is where fluorescent lighting is to be installed in an important control room where there is no natural lighting. In such circumstances it is necessary to provide a small motor-generator to give an a.c. supply from the emergency battery.

The list of substation batteries, Table 1, is already out of date: the number of substation batteries in service on the Manchester Corporation undertaking is now being quadrupled. For reasons of safety and convenience, there is now a much greater tendency to use electric power for the operation of circuit-breakers, rather than a spring-operated mechanism. I find from actual costs that, provided more than one circuit-breaker is to be dealt with, the battery is decidedly the better proposition. Moreover, the energy characteristic of a spring is not as good as that of a solenoid, for closing the conventional type of circuit-breaker.

Referring to Fig. 10, I consider it much better to light signal lamps by means of alternating current via a small transformer and to provide a switch to change-over the supply, either manually or automatically, to the battery in the event of the a.c. supply failing.

The author does not appear to favour automatic voltage control for trickle-charging, but in cases where it is necessary that the voltage should be held between limits of, say, 46 and 56 volts to ensure satisfactory operation of equipment, can he suggest a better alternative?

On page 231 he says that if the trickle charge be adequate then artificial discharge is unnecessary; but some manufacturers have recently suggested artificial discharge and recharge once per month. Perhaps there is some misunderstanding as to what is meant by "trickle charge" and "floating."

The author says very little about alkaline batteries, but they have some good points; for instance, lack of corrosive fumes is an important point for substation use, especially as many substation engineers prefer open-type cells. They also take up much less floor space, and in a recent case I found it necessary to recommend acceptance of alkaline batteries solely on that account. I am aware that the efficiency of the alkaline battery, on test, is lower than that of the lead-acid type, but in the case of a switch-house battery which has very little work to do the difference in the yearly efficiency is not very much; also the alkaline battery in such circumstances is easier to keep in good condition.

Mr. J. G. Beastall: Continuity of supply is of prime importance for telephone services, and the storage battery is relied upon to bridge any period of interruption of supply. With floating schemes it is the capacity required to tide over the period between failure of supply and the bringing-in of the emergency supply which determines the battery capacity to be installed, and adoption of the schemes mentioned in the paper makes possible a considerable reduction in installed capacity.

The author's reference to the supply failure at a bank is somewhat disturbing, and I should like to know whether the bank was taking a supply from two independent main generating stations.

The author says that telephone engineers place great reliance on specific-gravity readings. Does this imply that he has a useful alternative to suggest?

For giving an emergency standby supply a petrol engine coupled by a magnetic clutch to a motor-generator set may be used. The magnetic clutch is so arranged that it engages when the electricity supply to the motor fails, and the petrol engine, driven by the momentum of a flywheel on the motor shaft, then starts up and takes the load. I should be interested to know above what standby capacity the author considers it more economical to use such an arrangement rather than emergency standby batteries.

He states that the electric vehicle represents the cheapest form of mechanical transport, and I should like to know what assumptions in regard to cost of energy, period of depreciation of the battery and vehicle, and cost of maintenance, he has made as the basis of this comparison. Does his calculation take into account the provision of automatic charging facilities, which are sometimes installed with the object of cutting down the maintenance costs? Accepting the author's comparison of cost, I am still of the opinion that an increase in maximum speed and range is required to make the use of battery vehicles really attractive. Has any attempt to achieve this been made by the use of regenerative braking, and does the author think the limit has been reached in regard to the reduction of the power/weight ratio?

As regards the use of batteries as a standby supply for lifts, the majority of lifts in this country are operated on 3-phase a.c. supply with d.c. control. How would the author suggest we should obtain this a.c. supply? In addition to the battery, converting plant would be necessary, so that the complete equipment would be an expensive and very doubtful proposition.

Mr. A. Glynne: Whereas the curves in Fig. 17 show a finite and relatively slow rate of fall of terminal voltage immediately after the current has been switched on, the oscillograms which I have taken under conditions similar to those described by the author, but to a more rapid time-base, show that there is an instantaneous fall of voltage followed by a rapidly decreasing rate of fall.

I should like to ask the author whether he thinks that it is proper to regard this instantaneous fall as due to a true internal resistance, and whether he will give an account of what happens while the voltage is falling. Is the fall due to some form of polarization, or does the internal resistance rise?

Mr. H. C. Sabine: The author refers to the fact that a number of central-station batteries have gone out of existence, but it is interesting to note that those engineers who have kept their batteries have had the advantage of being able to use them to reduce their maximum demand and for emergency work.

Table 1 under-estimates the size of some of the batteries in service in the Manchester Corporation Electricity Department. Under the heading "Power stations," the third battery is of 2 000 ampere-hours at the 10-hour rate, and not of 1 000 ampere-hours. Under "Substations" the first battery is part of an old installation, installed in March, 1910. It has three boosters running in parallel, with the battery always on the busbars. I have seen the load rise from zero to 10 000 amperes in 20 minutes during one of the old-fashioned fogs.

The author states that the Bankside station had the first large standby battery. I think there were standby batteries before that, in use in central stations, but this was the first large standby battery to be trickle-charged.

The author describes a capacity test on (apparently) a whole battery; but in order to verify that a trickle charge alone maintains a battery at its full capacity it appears to me preferable not to discharge the whole battery. I am interested in a 1 000-ampere-hour battery which was installed in December, 1929, and has received a trickle charge of 0·2 to 0·3 ampere. This is even below the author's present figure, and much below the figure previously accepted. From time to time we have taken snap tests such as he describes, not on the whole battery but on certain different cells, and have obtained capacities of 105 % to 110 % from positives. On two occasions we have also discharged the negatives by the insertion of other fully charged positives in the same electrolyte, and obtained a figure of 200 %. The cells tested had never been discharged at all fully, except for the initial tests. Our tests suggest that the battery will maintain its full capacity more or less indefinitely.

Many switchgear batteries, especially those not employing contactors, have no low-voltage tappings for use when the battery is charged fully. It is not often that these batteries require charging. With a 230-volt battery, if it is necessary to give a quick charge and no low-voltage tapping is available the trip gear will get a nasty " bump " from a battery of 115–120 cells, which at the end of the charge will be standing at 300–315 volts. 275-volt lamps would also be overrun without a contactor. I should like to ask the author whether he considers a single low-voltage tapping desirable on batteries of 250 ampere-hours or more, both with and without contactors.

I much prefer trickle-charge contactor batteries, and am not so much in favour of the float-trickle charge, by which I mean the rectifier floating in parallel with battery and continuous load. The trickle-charge current is only of the order of 150–200 milliamperes, and the continuous load may be about 10 amperes. Thus, if one or two panels which have not been in use are started up and the floating charge is not increased, the battery will be discharged.

I think that it might be necessary for the emergency lamps to be on for more than 3 hours in the event of a bad failure.

With regard to explosions, I have only heard of one, which occurred in the corner of a battery room where a pocket of gas had apparently collected.

With regard to Fig. 17, I should be glad if the author would state the capacity of the cell used for each of these curves.

Mr. W. D. Sutcliffe: Does the author consider that a battery room ought to be kept at a definite temperature, both winter and summer; and has temperature variation any effect on the deterioration of the battery?

Is the specific gravity of the cell really a guide to its condition, and does the author consider it necessary to empty the cells and recharge them with fresh acid at any specified interval?

In my experience, no matter how carefully the motor-car battery is attended to it does not last more than 2 years. Is the shortness of life due to the vibration of the vehicle, or is an inferior type of cell used? If the cause is vibration, surely vehicle batteries should be subject to the same drawback.

Although one sometimes hears criticism of the motor spring-operated switch, scores of these have been operating with great success in this part of Lancashire for 15 years.

Mr. H. Shackleton: It is a matter of some difficulty to determine any economy in operation due to the batteries employed in connection with the public or traction supply of the undertaking to which Table 1 refers. In some cases they have enabled plant to be operated more economically, but against this must be set the capital and operating costs of the batteries. They have, however, been of material benefit in enabling partial supply to be given, particularly in the city area when plant has been shut down, either at times of light load or during emergencies. These batteries have undoubtedly proved a useful adjunct to the electrical equipment in the past, but with the progress of alteration in supply from direct to alternating current that function will disappear in the course of time. The same remarks would apply to the traction battery if the trams were withdrawn in favour of oil-engine buses. With regard to the other batteries listed in Table 1, however, they are considered to be essential to the satisfactory operation of the system.

It is regrettable that in many areas oil-engine buses are superseding tramcars. Tramway systems were usually supplied from rotating plant, located in a limited number of relatively large substations, via long d.c. feeders. Trolleybus systems, on the other hand, usually include many more substations with rectifiers for the same route length, the substations being located as near to the track as possible; this involves reduced losses in d.c. feeders. With the increased number of substations, and with the usual facilities for interconnection of adjacent sections of overhead line, the need for traction batteries is possibly reduced, and the difficulty in providing the necessary accommodation is materially increased.

It is suggested at the top of page 227 that batteries used for reducing bulk-supply charges without showing a profit would be justified because of their potential usefulness for other duties, including emergency lighting and switch operation and the driving of station auxiliaries and fire pumps. There is the possibility, however, that after the battery has supplied a fairly heavy load at peak-load time the remaining charge may be of a very low order. Interruptions to supply are liable to occur at times of peak load or very soon after, and reliance on the ability of a discharged battery for such important supplies as emergency lighting, and the driving of auxiliaries and fire pumps, leaves much to be desired. Undoubtedly, the best method of using a battery for auxiliary services in a station is to allow it to supply normally the momentary load, such as that required for switch operation, and in the event of a complete shutdown to allow it to supply emergency lighting and signal services.

Ambient temperature has a serious effect on battery performance. Outside-air temperatures of 11° F. were recorded during the recent cold spell, and exceptional demands were experienced on many supply undertakings. Batteries used for reducing peak-load charges are required to give their maximum output under such conditions. Without special provision for heating the battery house, the batteries will be operating under the worst conditions, and probably will be unable to furnish their rated outputs. In the particulars given on page 228 in connection with an installation at Heston and Isleworth, no mention is made of capital and running charges of battery-house heating equipment, or of the annual charges for the 400 sq. yd. of floor space occupied. If no special heating is employed, perhaps the author will give some idea of the battery's performance during the recent extreme weather conditions.

The following application of batteries in connection with emergency lighting may be of interest. A fairly high standard of illumination is desired in a small building in which no daylight is available. The premises are to be occupied continuously day and night, so that energy consumption is likely to be considerable. By the adoption of fluorescent tubular lighting, however, it is possible to reduce the estimated consumption to some 40 % of that required with the more usual type of light source. An adjacent building houses a battery which in the normal way will soon be superfluous. It is proposed to supply the fluorescent lighting normally from the a.c. distribution mains, and, in an emergency, from a small motor-alternator set energized from the nearby battery, the actual switching-over being effected manually. Two standard lamps permanently connected to the battery are included in the proposed scheme to provide sufficient illumination to enable the change-over from mains to battery supply to be carried out in the event of the mains supply failing. The use of a battery and a motor-alternator set in this way obviates the necessity for a duplicate lighting installation.

Mr. W. E. Swale: I should like to ask the author's views as to whether finality has been reached in the design of the lead-acid battery, particularly in regard to the types made for electric battery vehicles. It has been stated that there is a potential market in this country for 100 000 such vehicles: the number at present in use is about 5 000. Any hint as to possible improvements in the vehicle battery would be most encouraging.

The German Post Office is said to have about 22 000 electric vehicles in operation. Can the author state in what respect the batteries in these German vehicles differ from those used in this country?

If the need " to cater for these two absolutely distinct sets of conditions " (see page 238, col. 1) is adduced as an argument justifying the high cost of batteries, I suggest it is time this bogy was eliminated. Battery makers should agree amongst themselves on a reasonable life at which to aim, say 3 years. The user could then very easily be persuaded to accept this condition, and not to expect an unnecessary alternative.

The author states that the material of the battery, i.e. lead and the electrolyte (sulphuric acid), are the same now as 50 years ago. The output is still only about 9·5 watt-hours per pound of cell.

Would the author venture into the realm of prophecy and say whether any marked improvement is considered possible, for instance by putting up the batteries in steel cylinders under pressure? Unless some radical improvement can be visualized, it is difficult to foresee any rapid development for the electric vehicle beyond its present rather limited scope.

Mr. E. Jacks: Small garage proprietors require a small welding apparatus and invariably turn to the oxy-acetylene type, because in their particular circumstances the cost of electrical generating plant is not justified. Is there a possibility of their problem being tackled economically by the use of batteries? It has to be remembered that most small garages are already equipped with apparatus for the charging of batteries, and it represents idle capital now that the battery-operated wireless receiver has gone out of vogue.

THE AUTHOR'S REPLY TO THE DISCUSSIONS

Mr. E. C. McKinnon (*in reply*): Dealing with the points made by Mr. Constable, I have gathered from supply engineers that breakdowns in a generating station or supply station can be divided into two main categories, (*a*) those which can be rectified in a few minutes, (*b*) those which are unlikely to be cleared for several hours. The standby battery is effective for dealing with emergencies of the former category *inside* the station. Mr. Shackleton puts the position admirably.

Probably the fact that the storage battery was one of the main pioneer components of all electric supply plant accounted for the concentrated attention paid to its perfection during that period when electrical and mechanical engineers were handicapped in the development of other sections of the plant owing to the barrage of master patents and monopolies. One has only to examine photographs of electrical installations taken 40 to 45 years ago to see a practically modern design of battery in juxtaposition to almost primitive horizontal steam engines, " telegraph pole " generators, and quaint switchgear, mounted in some cases on wood panels!

The subject of submarines was intentionally excluded from the paper, but Mr. Constable has means for confirming that the capacity of present-day submarine batteries has been increased by 100–150 % per pound and also per cubic inch, compared with that of the batteries installed on the earliest American and European submarines.

The mean rate of discharge for a vehicle battery may be taken approximately as the 5-hour rate, and at this rate the correction for temperature is just over 1 % per degree Centigrade. The battery is warm after charging during the night, and retains a fairly even temperature on discharge during the day. It would certainly never fall to 20° F. (— 6·5° C.) in service in this country. Even if the temperature of the electrolyte fell to 0° C., the loss of capacity due to a temperature drop from 60° F. (15° C.) would only be about 15 %.

Mr. Good contributes what may be regarded as an addendum to the paper, on the subject of standardization for lighting equipments of air-raid shelters and control centres. Much has happened since the paper was written in March, 1939, but the international standardization of starter batteries must be deferred to happier times. It is a sad reflection that so many of the technical experts with whom Mr. Good and I collaborated on the most friendly terms at Brussels, Berlin and Torquay, in an endeavour to effect some standardization of storage batteries, must now be regarded—if only temporarily—as enemies.

Drs. Williams and Reynolds voice the view of battery makers on the question of multiplicity of types. So long as set makers build a compartment and demand a battery to fit into it, this elaboration of minor differences in design will continue. The popularity of portable receivers has greatly increased the number of types demanded.

Where conditions permit, I agree that glass containers are to be preferred, but there is a demand for cells in celluloid containers, e.g. for portable receivers, and celluloid lends itself to intricate designs, assuring non-spillable properties. Such cells, when made by reputable firms, are quite reliable.

The operation of a radio battery cannot be directly compared with that of a starter battery. The former is subjected to regular cycles, usually carried to exhaustion, followed by prolonged charges, conditions which do not make for maximum durability.

I am unable to give an account of recent improvements in accumulator design, as to do so would involve writing a new paper.

The underlying principle of emergency plant is absolute security, with cost as a secondary consideration. Mr. Fennell prefers to appraise emergency plant solely from the financial point of view, and would even appear to be prepared to sacrifice the interests of users by installing something cheaper, which he suggests would be satisfactory "accidents excepted." He belittles the utility of the batteries removed from central stations in the last 17 years, on the ground that their total capacity, say 50 000 kW for 3 hours, is only about equal to that of one of 160 "small selected stations." This is indisputable, but it can just as readily be argued that 50 000 kW spread over 160 stations would give to each an unfailing emergency output of 300 kW for 3 hours.

Mr. Fennell's strictures on the installation of an emergency plant at the Westminster Bank are hardly justified: the reasons for the installation of the plant are fully detailed in the paper.

I doubt whether there is in Eire any railway route, served by battery-propelled trains, where the battery is given a high-rate boosting charge automatically at each railway station along the route. On the Dublin–Bray section the battery receives a charge at the termini only.

I am in full agreement with Mr. Kidd's comments, including his point regarding the lighting of signal lamps. Trickle charging is a method of retaining a battery in a predetermined state of charge by passing continuously through the battery a current just sufficient to counterbalance open-circuit losses. These losses can be expressed in terms of ampere-hours, and for that reason the trickle charge is preferably based upon ampere-hour input. Even if the rate of charge is constant, the voltage of a cell may vary appreciably, e.g. through the effect of temperature. No manufacturer would recommend artificial discharge and recharge once per month for a battery receiving a continuous trickle charge.

"Floating" is the term applied to batteries permanently coupled across an electrical circuit, the number of cells and the voltage across the terminals of the battery being so adjusted that to all intents and purposes the battery receives neither charge nor discharge until some change of voltage occurs which causes the battery to discharge or to receive a charge.

I do not propose to deal in detail with Mr. Kidd's comparison between batteries of the lead-acid and alkaline types. If, as stated by Mr. Kidd, many substation engineers prefer open-type cells, this would rule out alkaline batteries. Alternatively, accepting that alkaline batteries in general are sealed-in, it would appear illogical to stipulate that lead-acid batteries must be of the open type.

In reply to Mr. Beastall, I am informed that the two "independent" supplies to the London bank mentioned in the paper originated from a common source.

As the fall in specific gravity is in direct proportion to the ampere-hours discharged, regardless of the rate of discharge, specific-gravity readings are only comparable for control purposes if the rate of discharge is constant and the fall in specific gravity at that rate of discharge is known. Voltage readings on discharge, in conjunction with specific-gravity readings, afford much better control of the battery.

Mr. Beastall refers to an emergency lighting supply obtained from a petrol-engine-driven motor-generator. Such a scheme is not competitive with a purely emergency battery on a cost basis, but merits consideration for dealing with emergency periods of long duration.

With regard to running and maintenance costs of electric vehicles, data have been published frequently during the past 18 months and can always be obtained from the Electrical Vehicle Association of Great Britain, Ltd. Simplicity of design and equipment has helped to bring down the cost of electric vehicles, and regenerative braking has been considered an unnecessary refinement. As regards Mr. Swale's query dealing with the prospects of development of the lead-acid battery for electric vehicles, no limit can be set in regard to the reduction of the power/weight ratio or the evolution of battery design.

A standby supply for electrically-operated lifts is regarded as essential and cannot be disregarded on the ground of cost, although, actually, schemes which are neither expensive nor complicated have been evolved.

Mr. Glynne's oscillograms are known to me, and by their aid some valuable information has been gained. The feature described by him may be attributed to increasing resistance due to a form of concentrated polarization in the active material of the cell electrodes.

There are arguments both for and against discharging the whole battery instead of merely a few cells, as suggested by Mr. Sabine. The former may appear unnecessary, but a periodical demonstration that the battery as a whole has its rated capacity removes any possibility of a false sense of security.

Mr. Sabine's figures might lead to the assumption that the capacity of the positives in the battery in question had increased by 5 % to 10 %, and that of the negatives by 100 %, on account of trickle-charge working. No increase in capacity can result from trickle charging, provided it is correctly adjusted.

In my opinion, tappings, or any other device likely to throw sections of an emergency battery out of step, should not be employed. The desired voltage-reduction could be obtained by the insertion of a suitable amount of resistance. The cells used for obtaining the curves produced in Fig. 17 had a capacity of approximately 100 ampere-hours.

In reply to Mr. Sutcliffe, no deterioration of a battery can, in this country at least, be traced to atmospheric temperature variations. It is only necessary to consider the warming of the battery room in winter if the full rated capacity of the battery at very high rates of discharge (say, $\frac{1}{2}$-hour, 1-hour, or even 3-hour) is required. In this connection, answering a point made by Mr. Shackleton, it was found advisable to install a special heating system in the battery room at Heston as a result of the first winter's experience; but as exhaust steam was available the expense was not a very big item.

It is unnecessary to exchange the electrolyte of a lead-acid cell at any stage in the life of the battery. The specific gravity of the electrolyte may be a guide to the state of charge of a cell, but is not necessarily an indication of its condition, unless by comparison with that of other cells in series with it.

Vehicle batteries are purposely of a more robust design than that of the average motor-car battery, and the latter is more susceptible to vibration. In recent times the average life of a car battery has been materially increased by important improvements in the method of charge control.

Mr. Swale is fortunate in finding that "the user can very easily be persuaded," an experience not shared by battery-makers' sales engineers. He has not appreciated the distinction dictating wide differences in design in, say, a light high-speed passenger car as compared with a 5-ton commercial vehicle. The German vehicle battery is of the Faure type, and is not very dissimilar from English Faure types, except that in recent years the components of the German battery have been of a very economical design and construction; and yet, although Mr. Swale finds it difficult to foresee any rapid development for the electric vehicle unless some radical improvement can be visualized, he states that the German Post Office alone has already about 22 000 electric vehicles in operation. If imports of cheap petrol were cut off from this country, or if as a matter of national economy the use of petrol were to be officially restricted, builders of petrol-driven vehicles would quickly turn their attention to the manufacture of electric vehicles.

In reply to Mr. Jacks, the practice of welding by means of energy drawn from batteries has been in commercial use in this country for many years. His assertion that the battery-operated wireless receiver has gone out of vogue is not supported by the statistics provided by Drs. Williams and Reynolds in their contribution to the discussion.

DISCUSSION ON

"FIRE-FIGHTING EQUIPMENT FOR ELECTRICAL INSTALLATIONS"*

BEFORE THE INSTITUTION, 25TH JANUARY, 1940

Mr. H. W. Swann: The work of the Electrical Research Association in connection with this paper arose originally from suggestions made to the Association, and follows as a natural corollary to the recommendations of the Electricity Commissioners' Fire Risks Investigating Committee. At the time when those recommendations were issued there was a dearth of precise knowledge as to the performance to be expected of certain forms of media and the suitability of particular media for particular locations. For instance, some engineers concerned with the operation of electrical stations seemed convinced that carbon dioxide was the best form of fire-fighting medium for any situation, indoor or outdoor, whereas other engineers would hear no good word for anything but water.

At the outset of the work the E.R.A. found that a good deal of ground had been covered in Paris, and that some decisions had been taken already which had been based on large-scale experiments. I attach a good deal of importance and value to the information which I acquired in Paris when, as Chairman of the E.R.A. Committee, I visited some of the supply stations with Mr. McMahon and had the advantage of first-hand accounts of the experiments from M. Lemoigne and several other French supply engineers who had gone very thoroughly into the matter. The Committee decided, however, that some further work was necessary in this country; and I have to make acknowledgments to the County of London Electric Supply Co. for their great courtesy in allowing facilities for large-scale experimental work at their Barking station, where artificial fires have been created and various forms of fire-fighting media tried against them. The results have been recorded from observations made, and mainly by means of colour films, though a few of the earlier tests were recorded on black-and-white films. These are of a most interesting and instructive character.

The arrangement and direction of this experimental work at Barking has been entirely in the hands of Mr. Hacking (the Chairman of the Sub-Committee) and Mr. McMahon. Mr. McMahon wishes me to emphasize the following points in connection with the make-up of the film to be shown:—

(1) The film as shown consists of less than 10 per cent of the film exposed during the tests, which amounted to a total of nearly $1\frac{3}{4}$ miles.

(2) The majority of the tests made were successful, but the less successful ones have been illustrated because they are more spectacular and in fact provide more experience from which data may be drawn.

(3) The indoor tests were no less useful than the cable-gallery or outdoor tests, but photographic conditions are such that it is impossible to do them justice by cinematography. The film would appear incomplete without any reference to them, and for this reason two have been illustrated for purposes of record.

Mr. R. A. McMahon then gave a commentary on the tests and illustrated it by a cinematograph film in colour.

Mr. H. Nimmo: The paper will stand as a very useful companion to the report issued by the Electricity Commissioners' Fire Risks Investigating Committee. The two should be read together, but I think the E.R.A. one may require a little amendment to bring it into line with its elder brother.

The great risk with which we have to contend is that of an oil fire, and the film shows how great that risk is. Some people may say " Why not minimize this great risk by installing oil-less switchgear?", and I have heard our manufacturers criticized for not developing oil-less switchgear more actively. This is not the time to debate the merits of the oil switch; the fact remains that a very large number of the stations in this country are equipped with switchgear which is oil- and bitumen-filled, and it is the duty of electrical engineers to take measures to combat the fire risk associated with such gear.

There are two passages in the paper, on pages 733 and 734, which give the impression that a portable installation is suitable as an alternative to a fixed automatic equipment. I am of opinion that a portable installation by itself is absolutely useless unless trained firemen are kept in readiness to attack a fire immediately it occurs; but this is not practicable. I base this opinion on the result of investigations which it has been my privilege to make into a number of fires at generating stations. In all these cases portable equipment was available, but in no case was it possible to use it effectively. An oil fire starts so rapidly and is so fierce that in my opinion nothing but a fixed automatic equipment is suitable for dealing with it, though portable appliances may give useful back-up protection.

For dealing with oil fires in switch-rooms, indoor transformers, outdoor transformers and underground substations, the Fire Risks Investigating Committee recommended fixed equipment, and in addition portable equipment consisting of (1) hand appliances and sand, and (2) hose and gear to enable foam or water sprays to be produced and applied manually. The E.R.A. tests have only confirmed my opinion that these minimum requirements are very necessary.

The paper shows that all the various forms of media which were used in the tests could be successful if properly applied. It must be remembered that these tests were applied by experts, the manufacturers; but the user is still left wondering which system he ought to apply for the protection of his own installation. There are drawbacks to all the systems, but water properly applied is, I believe, the most certain means of putting out a fire of whatever kind, and the cooling effect of water gives it a tremendous advantage over foam, carbon dioxide, methyl bromide or carbon tetrachloride. If this were generally agreed, the problem might be solved by saying that (*a*) for outdoor and indoor transformers and oil- and bitumen-filled switchgear, automatic atomized-water installations must be installed; and (*b*) for cable basements, cable tunnels and such places where oil is not likely to be present, ordinary water sprinklers must be provided.

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* Official communication from the British Electrical and Allied Industries Research Association (see *Journal I.E.E.*, 1939, 85, p. 719).

The paper suggests that in an atomized-water installation 4 or 5 minutes' supply of water should be available, at a pressure of not less than 50 lb. per sq. in. I should prefer to see at least 10 minutes' supply of water available, and at a slightly higher pressure of, say, 60 lb. per sq. in., because that would give a rather greater factor of safety. This is very important, and in many cases it will mean the provision of special pumps: great care must be taken in the design and layout of the pumping plant to ensure that the pumps will function even if the power station shuts down as a result of a fire.

Mr. C. M. Kerr: Back-up protection is the subject of only a short note on page 734, but the film which has been shown indicates that it is an essential and very important factor.

There are two points which I should like to mention that may serve to stimulate discussion. The first is that it is necessary to consider the effects of an explosion which might be caused by electrical faults on the various media that may be used. Some types of media might stand the explosion better than others. Secondly, no reference has been made to the question of the maintenance of fire-fighting equipment. This is a point to be considered, as no doubt some types of media will require much more maintenance than others.

Dr. S. F. Barclay: The essence of the recommendations concerned with water as a fire-extinguishing medium is the stipulation that a running pressure of not less than 50 lb. per sq. in. should be provided at the discharge nozzles. I cannot too strongly emphasize the wisdom of, and the need for, this stipulation. Provided nozzles of appropriate design are used, water issuing under this pressure will impact on to the surface of the oil with such force as to form a non-burning emulsion and flame extinguishment must result under all conditions.

Whereas low-pressure water discharge must fail under average actual fire conditions, it can succeed under certain forms of test. The oil vapours arising from burning insulating oil have a narrow range of inflammability, so that until they have been diluted by air in the necessary proportion they are asphyxiating and not combustible. Even a light spray of water may momentarily beat down these heavy asphyxiating vapours and so extinguish the flames, leaving the experimenter deceived as to how the extinguishment has been achieved. To determine *specific* as compared with *environment* extinguishing power the element of self-asphyxiation must be eliminated. If the E.R.A. Committee will make a test with cold insulating oil in a shallow tray 3 ft. 6 in. in diameter (say), they will find it impossible to extinguish the fire by the use of water until the pressure has been raised to the value at which emulsification of the oil results. Such a test would eliminate some of the misleading factors present at the Barking tests, which were of necessity restricted in scope, and would show the Committee the vital importance of insisting on the use of high-pressure water.

I should like to mention that the emulsification of oil for fire-extinguishing purposes is the subject of a British Patent.*

(*Communicated*): It appears that of the two systems tested, employing water only as the extinguishing medium, one used high pressures and the other low pressures. In the course of the discussions at the various Local Centres, reference has been made to the fact that according to the detailed report of the tests (E.R.A. Ref. V/T7) satisfactory extinguishment was apparently achieved with the low-pressure as well as with the high-pressure system, but the Committee nevertheless recommend high pressure as an essential of success. It is important that this apparent discrepancy should be explained.

In one respect the Barking tests were not conducted under what may be described as normal conditions. In all these tests the oil was highly heated, the object being to favour its burning. With most extinguishing media the use of hot oil would be fully justified, but it cannot be adopted where water is employed, if extinguishing merit is to be truly assessed; for a new factor is introduced—the phenomenon of "frothing." When water is sprayed on to the surface of highly heated oil, the water-drops are rapidly raised to the boiling point as they sink into the oil: steam is also generated if water is introduced under the oil. As the steam breaks through the surface of the oil an immense number of small oil-film bubbles are formed. The oil vapour rising off the surface of the oil to feed the flames passes into these bubbles along with the steam. The vapour is thus trapped in the mass of bubbles, or froth as it is called, and so combustion ceases. If hot insulating oil be lighted and water be introduced under it, the fire will go out in 3 or 4 sec. by froth formation without any fire appliances whatsoever being necessary. There is the same result if water at low pressure is sprayed on to the surface of the oil, and extinguishment due to froth formation can well be misunderstood unless a further test is made with cold oil, when it will be found that the water spray is without effect.

There is a minimum critical temperature to which oil must be heated for frothing to be possible: the value for insulating oil is approximately 320° F. With all the tests at Barking, the oil was heated to at least this temperature: water was introduced under the oil to cause overflow from the transformer tank and water was sprayed on to it, so that heavy frothing must have resulted, giving flame extinguishment from this cause alone. Such a result is not to be expected from low-pressure water discharge with actual fires, since rarely would the mass of the oil be heated to 320° F.

The froth is composed of a mass of bubbles with walls of oil film and charged with water vapour and oil vapour:

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* British Patent No. 380102.

froth is thus not to be confused with an emulsion, which is a dispersion of tiny solid globules of oil in water.

The statement is made in the paper, on page 723, that "Water . . . causes extinction by cooling." This statement may be widely misunderstood in the absence of further explanation. The cooling action of water is mainly due to its wetting properties, but water does not wet oil, and the cooling action of low-pressure or of "atomized" discharge is less than the heating from the fire: a thermocouple under the oil surface will show that the oil temperature steadily rises under such conditions. The one method by which water can be applied that will give rapid cooling is to direct it on to the oil with sufficient force to break up the surface into an immense number of tiny globules and thereby increase by several hundred times the oil surface presented to the water for cooling contact. There is a critical impact value necessary to bring about this result; and, of the several factors involved, high pressure is one and correct nozzle design is another.

As the minute oil globules are formed, they are dispersed in the water phase and each is coated with a film of water, so that not only is the fire extinguished and the oil cooled but re-ignition is discouraged. This emulsion formation—for such it is—can be verified in a variety of ways, but perhaps most conveniently by hydrometer readings.

Thus a critical study of the underlying principles confirms the Committee's recommendation to employ a minimum running pressure at the discharge nozzles of 50 lb. per sq. in.; but high pressure in itself may not ensure success. The water-drops must have the necessary mass as well as the necessary initial velocity if they are to travel through the air against the atmospheric disturbances caused by the fire—perhaps against strong wind—and still retain adequate momentum. If the water pressure is too high, in relation to nozzle design, the water is atomized and the carrying power of the jet diminished. The recommendation would be on surer ground if it went on to say that the nozzles must be so designed and disposed as to give emulsion formation at substantially the whole of the burning surface.

Mr. G. O. McLean: I should like to say a word or two about detectors, for, after all, our best anti-fire weapon is prevention. The paper does recommend smoke detection, but the paragraph in which it does so is such a small one that the recommendation may be overlooked. Smouldering generally occurs before a cable burns out. Cable basements and even modern switch rooms may not be frequently visited, and therefore a smoke detector is very valuable, as it gives ample time for investigation and the necessary manual action to prevent an actual fire occurring. To give an example of the volume of smoke and the speed of detection, I should like to cite an installation in a selected station in Mid-East England, where it was possible to test the installation by someone lighting and smoking a cigarette in a controlled area, and for the observation to be made in the control room, two floors higher up, before that cigarette was half finished.

I should be interested to know what depth of gravel-filled pits is required to extinguish burning transformer oil, if it is impossible to drain the oil away. Some London supply undertakings are limited as regards room, yet have to try to devise some means of extinguishing a possible fire of that type. Some of them allow 1 ft. of gravel above the maximum possible oil-level. Have any tests been made of this method, and, if so, what results have been obtained?

Mr. R. W. L. Harris: I should like to make one point with regard to recommendation A(*b*), which refers to the application of atomized water to weatherproof metalclad gear installed indoors. In general, weatherproof gear is more expensive than its indoor equivalent, and is normally either installed outdoors or only partially protected by means of buildings. It seems, therefore, that the applications of water-spray protection to weatherproof gear indoors must be somewhat rare, and if such spray is used on normal indoor equipment, not built to withstand the weather, each case will have to be considered on its individual merits; and the remarks in Section (11)(*a*), in regard to the possibility of shutdowns due to temporary breakdown of insulation, will apply with particular emphasis.

The preheating of the oil in such tests as these is important to ensure that they are sufficiently stringent, and its use has resulted in extremely satisfactory fires in this series of tests. Anything that will prevent the oil from heating-up in practice will have a great bearing on the limitation of damage due to fire, and the application of complete and effective protective systems to all zones in order to prevent sustained arcing is of paramount importance. Such systems have been described in a recent paper on "Safeguards against Interruptions of Supply."*

With regard to cable tunnels, these form one of the most likely fields for the extended use of smoke-detection equipment. The paper brings out two other important points, namely that there should be no blind spots to which the fire-fighting agent cannot get, and that there should be no material present which would be likely to smoulder after a fire. As an indication of what can be done in this latter connection for low-voltage cables it may be mentioned that a mineral-insulated, copper-sheathed cable is now obtainable which cannot smoulder and is unaffected by being heated-up to temperatures below the melting point of copper.

Mr. D. H. Chisholm: I do not subscribe to the theory of emulsification propounded by an earlier speaker.

I was present during Tests Nos. 41–44 inclusive, employing atomized water. Some observers thought that in Test No. 43, for which a time of 1 min. $51\frac{1}{5}$ sec. is given in the paper, fire was actually extinguished in 9 sec. with 35 gallons of water. The installation was left in operation beyond that time to see whether the firing wads would be extinguished. These wads were, in fact, extinguished in two tests out of three on the transformer structure. In Test No. 44 the extinguishing time appeared to be somewhat less than 27 sec., but Mr. McMahon, the E.R.A. observer, was not able to approach the structure closely enough to get a full view because of the ground fire which was in progress, owing to the severe boil-over having spread the fire beyond the protected zone before the projectors were turned on. I should be glad to have confirmation of those points.

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* *Journal I.E.E.*, 1938, **82**, p. 445.

I am not in agreement with the statement (page 733) to the effect that the water pressure should not be less than 50 lb. per sq. in. at the projectors. During Test No. 44, for example, the pressure at the nozzles was 16 lb. per sq. in. after making allowance for pipe friction, yet it will be readily conceded that the performance was satisfactory. A close inspection of the film of Test No. 44 shows that the ground fire which occurred at the boil-over before the extinguishing system was brought to bear, was extinguished well beyond the direct range of the projectors. This extinguishing action was due to steam rising from the discharge, and is not a function of the applied water pressure.

As for the continuance of the burning of the firing wads, I am accustomed to seeing immaculate cleanliness in generating stations and substations, and I do not consider this lesson to be of great value.

It seems that the value of the test-house fires may be limited by the fact that practical conditions were not simulated. In practice an arc under oil gives off approximately 80 per cent hydrogen, which requires a minimum concentration of 5·9 per cent oxygen for its extinguishment. Petrol, for example, will burn with a minimum concentration of 15 per cent oxygen. I think that the risk is very great, and that the tests would be of greater value had they been applied to an actual switch fire, more particularly as they relate to inert-gas extinguishing systems.

Mr. G. Lambert: It is stated in the paper that the cooling effect of gas is practically negligible. I agree that carbon dioxide does not extinguish by cooling so much as by blanketing, but in five tests where carbon dioxide extinguished the fire there was an average drop of 30 deg. F. in the temperature of the oil between the start and the finish of the test. This is certainly not negligible.

It seems a pity that in none of the gas tests was it possible, apparently, to determine how long it took to put the fire out. One is led to believe that the fire may just have flickered out at the end of the discharge. In one test on the outdoor transformer where the total time of discharge of carbon dioxide was almost 2 min. I estimated that the fire was out within 15 sec. Mr. McMahon said that because of low visibility it was difficult to determine when the fire was out; my experience is that extinguishment occurs when there is a characteristic dense cloud of carbon dioxide completely overwhelming and filling the space.

In Table 4 there is a reference to the use of portable hand-trucks, one of which was fitted with 100 lb. of carbon dioxide. The paper states that 100 lb. was used to put out the fire in the cable gallery, and that the fire was put out in 27 sec. With that particular truck, however, which has a full discharge time of 1½ min., 27 sec. represents the use of about 30 lb. of carbon dioxide.

With regard to thermostats, I admit that it is very difficult to plan the positioning of the thermostats or heat-operated units so that they are not shielded by the apparatus itself, and if the E.R.A. still have their fire apparatus in commission I suggest that they might carry out some research on that matter.

Probably the most rapid way of detecting fires in their initial stages is through the presence of smoke, but one would hesitate to use smoke detection as a method of discharging any extinguishing system, because it is so fast. There may be instances where smouldering of hot cable occurs, and if smoke detection is used for discharging the extinguishing system this may be discharged before there is really any necessity.

I am struck by the absence from the paper of reference to any difficulty with gas systems due to wads remaining alight when the fire is nearly out.

Mr. W. Dundas: The tests carried out by the E.R.A. are of considerable interest and value to those concerned in determining the methods to be adopted for protection against fire in power stations, substations, etc., and I am in complete agreement with Mr. Nimmo on the question of the desirability of fixed automatic fire-fighting equipment. It is surprising how much dense black smoke can be produced from burning bitumen in a short space of time, and this may make it impossible to use portable extinguishers. That does not mean that portable equipment should not be provided—far from it, for it has proved valuable in very many instances—but it cannot be expected to deal with outbreaks of fire of any magnitude.

In choosing the type of equipment to adopt, consideration must be given to the possible damage that may occur to the electrical apparatus. Gas, of course, does not cause damage, and whilst I do not propose to discuss the merits or demerits of one system compared with another, I do strongly deprecate the indiscriminate use of water on metalclad switchgear, for it has an unfortunate knack of finding its way in, even though the designers take every precaution in the construction to eliminate the ingress of moisture.

As regards the necessity for draining oil from transformer pits, care must be taken to ensure that oil cannot find its way through cable ducts into cable tunnels or basements. The same applies to transformer installations protected against fire by water; a serious case of flooding occurred even when adequate provision had been made for draining the oil. Gravel pits around transformers, with their tendency to collect dirt and possible inflammable material, are not required when water sprays are installed. A plain concrete flooring makes a more satisfactory and clean arrangement.

The supporting steelwork provided for carrying the spray nozzles has always appeared to be a somewhat flimsy arrangement, and it would be interesting to know whether any signs of damage thereto were observed after the tests at Barking.

Mr. F. H. Sharpe: The paper contains excellent recommendations as to what plant to provide, but I am sorry to see no advice to the purchaser how to use it. One problem confronts every user of plant of this type: What is the first action to be taken when a fire breaks out? Is the water, the carbon dioxide, the methyl bromide or whatever it may be, to be turned on immediately, or should the personnel be got out of the danger zone first?

The problem is easier now, because smoke detection has come to stay. The early warning which is given makes it possible to have a distinct understanding about clearing switch-houses and so on, and gives more time to do so. If, however, we had to rely on the older heat-detector methods of announcing fires, I for one would rather run the risk of being drowned, suffocated or gassed, than roasted. I believe the ultimate danger to life to be less if the fire is tackled speedily because the fire staff will be equipped with respirators, etc., and can remove without delay operators injured or affected by fire, fumes or gases used for fire-fighting. If the fire is still raging rescue work must be delayed, if not precluded.

It seems to me, therefore, that one of the points of greatest importance in the problem of fire-fighting is the organization in connection therewith, in particular the matter of "permits to work," for someone is usually working on some job or other in a large switch-house. It would be very helpful to know what are the recommendations of the E.R.A. in this connection.

I am glad to see that the bogy of the ill-effects on health of methyl bromide has been laid by the London County Council.

I endorse what has been said about the necessity for fixed installations. It is no use asking any man to tackle a big fire with, say, a portable hose, but portable equipment should be there for "mopping up," and to deal with such odd occasions as when a blow-lamp is knocked over. With regard to cotton waste lying about, Mr. Chisholm is much more optimistic than I am. I am afraid that it really does take a very firm hand to keep dirt out of switchgear and transformer compounds. I drew attention to this a few years ago. I myself have seen what might have been a very serious fire caused by smouldering waste; fortunately it was detected in time.

Mr. F. P. Spicer: No definite recommendations have been made as to where the fire-fighting pipes should be placed, and it occurs to me that in considering the relative merits of water and of gas it would be helpful if it could be stated whether the pipes used for gas were more or were less obstructive to the plant protected than those used for water. I gather from photographs that the water pipes completely surround the transformer, but the pipes for the gas seem to be considerably farther away. It would be useful to have some guidance on how in practice that affects the working of the plant or station which is to be protected.

The previous speaker has referred to the laying of the old bogy with regard to the relative merits of certain gases. I have always understood that comparatively small quantities of methyl bromide, and never more than 5 per cent, were required compared with carbon dioxide; but in the case of the tests which have been put before us, notably in Tables 5 and 6, in one case 24 lb. of methyl bromide was used and in the other 48 lb. These represent percentages in atmosphere of 7·6 and 15·2 respectively. In a publication which is in my possession it is stated that independent observers have, as the result of careful research, found that the average figure for rapidly fatal effect caused by half an hour's exposure is between 0·2 and 0·4 per cent. As I am told by our chemists that the effect would certainly be not less than in inverse ratio to time, this means that a man in the larger concentration would die in 24 sec. and in the other in 48. This being so, has the bogy really been laid?

Mr. H. Bright: Although the title of the paper is "Fire-Fighting Equipment for Electrical Installations," both it and the discussion have concerned themselves almost entirely with fires at generating stations. The potential risk to life from fires in transformers and oil switches installed in places of entertainment and office buildings is far greater, and a knowledge of how to deal with such fires is very important. Of the various methods of attack, those using gases seem to be ruled out because of their toxic or suffocating effect. When transformers are installed in buildings it is difficult to arrange for drainage of the oil, and the usual practice is to tank the floor to a depth sufficient to hold the total quantity of oil. Water appears to be a suitable and effective material for attacking fires, but if this is used it seems that the capacity of the tanking must be increased sufficiently to hold the water as well as the oil, as the latter would float on the surface and eventually escape into the building. Unless some means of limiting the total amount of water used is provided, the capacity of the tanking will have to be infinite. There is a great need for guidance in selecting fire-fighting equipment for such conditions.

Mr. V. G. W. Gilbert (*communicated*): With fire-fighting systems which depend on the use of water jets, certainty of extinguishment of an oil fire depends on those jets not being displaced from the positions fixed for them in the original design of the installation. If even one jet be dislocated by the explosion which usually precedes the conflagration, not only will the fire be not extinguished, but it is probable that it will be not even controlled. Further, it has been shown that failure of extinguishment or control results in the actual extension, by flowing, of the burning-oil surface. Another consideration which can by no means be ignored is that efficiency of operation is possible only between relatively narrow limits of water pressure. I would ask whether such slender margins can be guaranteed in the circumstances—usually adverse—obtaining in the average accidental outbreak of fire in electrical plant, putting aside the much more serious conditions attaching to fires following aerial attack.

The effect known as "boil-over" is due to the presence of water in the oil; and, in the case of transformer oil, it is inconceivable for water to be present unless it come from external sources, i.e. the sprayers in the case of a water fire-fighting system.

What of portable, i.e. hand-directed, water jets? In view of the risk of shock, manually-applied water streams, when dealing with electrical fires, are safe only in the hands of experts. Expertly handled, spray nozzles for applying water can often be extremely valuable.

My experience has shown that fixed installations for ejecting CO_2 from nozzles over indoor switchgear, transformers, etc., are not subject to the drawback which applies to water jets, namely that the disarrangement of one or more nozzles is bound to jeopardize seriously the chances of extinguishing the fire. CO_2 systems for protecting outdoor plant are liable to be rendered inefficient owing to dislocation by explosion. On the other hand, CO_2 does not carry with it the risk of spreading the burning-oil surface, as in the case of water. Hand-directed CO_2 jets do not possess a cooling effect equal to that of water; nor are they usually effective over as great an area.

It would be interesting to compare, for a given electrical installation, the costs of methyl-bromide, CO_2, water, and foam protection systems. Seeing that methyl bromide costs over 5s. per lb., as against 4d. per lb. for CO_2, does the total cost of a methyl-bromide installation compare favourably with that of a CO_2 installation?

I am inclined to question the statement (page 733) that "there is no more risk to the health of the operator with methyl bromide than with CO_2 alone." When methyl bromide is employed in fire-extinguishing apparatus, there are two points which must be borne in mind: (1) the danger of poisoning, in the case of a fixed installation for an indoor risk, in the event of discharge of the gas when no fire has occurred; (2) the risk of poisoning by the decomposition products of methyl bromide after it has been applied to a fire. Hamilton* points out that methyl bromide causes more or less permanent damage to the nervous system in human beings, but disappears so quickly from the organs and fluids of the body as to escape detection at autopsy. It is generally believed that prolonged exposure to a concentration as low as 2 per cent in the air would lead to serious poisoning symptoms. The main danger appears to be the delayed toxic effect, no symptoms appearing for some time after exposure to the gas, but serious poisoning symptoms setting in later.

Dealing with fire-extinguishing apparatus employing foam, my experience is that, in the case of fixed installations, provided all of the foam-discharge devices have not been completely destroyed by the initial explosion (a very rare contingency), control of the fire may confidently be expected. Even if the foam-discharge devices have been seriously damaged or dislocated, the foam that reaches the fire will exercise a marked blanketing and controlling effect, sufficient to ensure that the remainder of the fire can be dealt with by portable foam jets. This view is supported by the results of Test No. 31, Table 9. The fire staged for the purpose of the test was severe. Only one hand-directed jet was applied, a robust chemical foam being thrown on to the fire. Extinguishment took place in 2¼ minutes, after the application of about 1 000 gallons of foam. It is interesting to contrast this with Test No. 35, in which two air-foam jets were employed. The time required for extinguishment was much the same, but more than 3 times the amount of foam was required. Air foam is more fragile, and lighter, than chemical foam, and, in my experience, offers best chances of success if employed in the form of a fixed installation. In portable chemical-foam systems for outdoor transformers, the appliance for producing the foam can operate satisfactorily within wide limits of water pressure. Thus one of these instruments, at 35 lb. per sq. in. water pressure, will produce, per minute, about 800 gallons of foam; and at 100 lb. per sq. in. about 1 600 gallons. It is probable that only in special instances would foam installations be suitable for indoor electrical risks. In such cases my own preference is for the CO_2 system.

Mr. E. Hill (*communicated*): The tests described in the paper did not in my opinion deal in sufficient detail with the indoor oil risks. A substation building is usually situated in a densely populated area where damage and loss of life from fire may be considerable, but an outdoor substation can as a rule be dealt with by the local fire-brigade using portable equipment. For fixed outdoor installations water alone should be recommended, however, as it is not affected by weather conditions.

Fire risks would be much reduced if engineers did not operate plant under overload conditions. In many cases the additional expense incurred through inefficiency would be a small premium to pay for insurance against breakdown and fire.

The recommendations state "where weatherproof gear is installed atomized water will provide adequate protection." Surely an engineer should not be asked to meet the expense and loss of flexibility associated with weatherproof switchgear to be housed in an expensive building; it would possibly be far cheaper to install oil-less circuit-breakers. For existing indoor equipment, gas, with its comparative freedom from damage to other equipment not affected by the original outbreak of fire, would be first choice. Gas will penetrate into any part of the building, even to cables carried at ceiling level, in which case the application of water would be difficult.

The tests covered for the most part the normal fire risk encountered wherever hot oil is used; possibly this is the type met with every day by the oil-refining industry, whose experiences would no doubt be of great value.

The violent explosion that usually precedes an electrical fire has apparently been ignored; surely piping and apparatus placed in certain positions might be damaged, and the extinguishing system completely unbalanced, by such an explosion. Where water is used the atomizing feature might be cut off and large quantities of water would then flow, covered by burning oil.

The tests did not deal with the planning of an installation, which in my opinion should have been their main object; for manufacturers of extinguishing equipment have dealt for many years with oil fires but not with combined oil and electrical fires. Possibly co-operation with the manufacturers in the designing of substations to prevent outbreak of fire and to extinguish fire would lead to greater safety. In many cases the fire-extinguishing equipment is added as an afterthought.

The toxic effects of CO_2 are in my opinion overrated. I have been present on two occasions when manually operated CO_2 equipment has been used in switchgear fires, and in each case it was possible to enter the switch-room less than 5 minutes after operation (i.e. before ventilators were opened).

In conclusion, I suggest that the E.R.A. would be doing valuable work if they collected information from all sources concerning electrical fires and the associated electrical factors.

Mr. J. W. Leach (*communicated*): The paper rather ignores the defects and dangers of water fire-fighting systems as applied to electrical plant, particularly in view of the damage that water inflicts on electrical insulation. The E.R.A. attitude on this matter is revealed in the suggestion that weatherproof gear should be used for indoor substations because in the event of a fire they may be sprayed with water. The real situation is that indoor gear exists in our substations and therefore water must not be used for fire-fighting purposes.

The paper omits to mention that physical separation, either embodied in the initial layout or provided in the form of barriers, walls or screens, is of fundamental importance. Barriers limit the spread of fire and damage due to explosion, and no better demonstration of this is needed than the last fire shown on the film. A set of screens and a dam wall round the transformer tank would at least have saved the five 40-gallon drums of spare oil which the hydrants were unable to rescue.

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* "Industrial Poisons in the U.S.A."

One type of water fire-extinguishing plant requires a pressure of 60–90 lb. per sq. in. and another only 16 lb. per sq. in. The feeling of the E.R.A. seems to be that 50 lb. per sq. in. is an indispensable minimum. In this type of plant we require (*a*) an unfailing supply of water, (*b*) an unfailing pressure of supply (usually provided by an electrically-driven booster pump), (*c*) anti-freezing equipment (usually requiring an air compressor), (*d*) an unfailing electricity supply for (*b*) and (*c*).

With regard to (*a*), the town main cannot be regarded as an unfailing water supply, as regards either quantity or pressure, and in these days of possible military action large water storage tanks must be installed.

As regards (*b*), the fire might be preceded by an explosion, which, if it damaged the pipelines or nozzles, would result in loss of the essential pressure, with consequent flooding.

Anti-freezing measures, (*c*), involving filling the pipes with compressed air, may be a somewhat doubtful form of protection in practice, particularly in such severe weather as is now being experienced in this country.

With regard to (*d*), the working of all the equipment depends upon the presence of a supply of electricity, connecting cables and motors, any of which may be involved in the breakdown or fire which is to be dealt with.

Without entering into the theory of how extinguishing takes place, whether it be emulsification, plain cooling or blanketing with steam, the essentials of successful extinguishment with water appear to be a prompt, unfailing, and plentiful finely divided spray of water, directed into the right place and thoroughly blanketing the fire.

Commissioning tests of fire-fighting equipment, preferably full scale, are desirable, even if only to give confidence to the attendant staff; but such tests on site are practically impossible where water apparatus is installed to protect switchgear, and there is no satisfactory means of making sure of the correct distribution and placing of the nozzles. This disability is serious also in that it prevents proper routine tests of a complicated installation.

From the tests shown, the foam systems appear to be unstable in regard to density of foam, and to lead to great difficulties in extinguishing if the foam becomes wet. I think the greatest use of this system in manual operation is for back-up or mopping-up purposes, and in this connection it was interesting to note in the film how readily the portable foam equipment dealt with the cable-gallery fire. It has no advantage, even in this field, over CO_2 apparatus.

The deductions regarding CO_2 gas seemed to be based on Maker C's results; I am at a loss to understand why more weight was not given to Maker B's results, since his equipment completely extinguished every fire to which it was applied.

The basic criticism of inert gas seems to lie in the suggestion that the fire may restrike after the gas has been discharged. This is shown in one case in the film and is followed by a most spectacular demonstration of the unfortunate effect of hydrants as a back-up measure. It is modern practice to take advantage of the physical subdivision of the protected equipment and make a corresponding sub-division of the gas without extra cost, so providing at least two shots of such gas equipments; I suggest that the result would have been much better, if less spectacular, had a second shot of gas been used as standby instead of the hydrants.

The great merit of inert gases, namely their non-damaging property, has not been given its due weight in the recommendations in Section (12). This feature is of primary importance in the matter of restoration of supplies. I have recent experience of a dangerous fire which resulted in a momentary shutdown, but by good fortune failed to operate the water installation before it had been dealt with by portable extinguishers. The damage in this case was limited to the faulty switch, but had the automatic water equipment operated the episode would have been succeeded by at best a long and anxious period of reconditioning the whole switchboard, and at worst by a major shutdown. As regards the quantity of medium available, when the practical difficulties already mentioned with water supplies are taken into account, the CO_2 system is seen to be far simpler, more reliable, easier to test in a satisfactory manner, and more likely to function correctly when the emergency arises. It is an independent self-contained unit system, depending in no way on outside supplies which may fail at the critical moment. It is not affected by frost, and is reasonably economical in regard to cost and space. In the case of small substations there is no other practical or economic alternative.

Before coming to this meeting I had a certain sneaking faith in hydrants as a last resort, but having seen on the film the serious conflagrations that can result from attempts to use hydrants I cannot understand the logic that interprets this evidence as supporting their use.

The general tenor of the comments and discussions on this subject gives the impression that attention is being concentrated on large installations; but when small installations of, say, 300–2 000 kVA capacity, such as may be found on consumers' premises, are considered it will be seen that it is quite uneconomical in money and space to provide water systems and their necessary accessories; in fact, inert-gas installations are the only solution. The cost of a typical CO_2 equipment for a substation of 500 kVA capacity works out at about £50 to £70, a figure which cannot be approached by a water installation.

If it is possible for the E.R.A. to carry out any further tests, I should like to see them made in the case of transformers by preceding the oil fire with an explosion to rip open the transformer tank, and in the case of switchgear on actual equipments of the compound- and oil-filled type. There need be no difficulty in obtaining such switchgear.

[The reply of Messrs. J. Hacking and R. A. McMahon to this discussion will be found on page 276.]

MERSEY AND NORTH WALES (LIVERPOOL) CENTRE, AT LIVERPOOL, 5TH FEBRUARY, 1940

Mr. E. L. Morland: The fixed type of fire-fighting equipment, controlled by automatic action, discharges the extinguishing media more quickly than the portable type, which is usually handled by the personnel of an undertaking. Speed of operation is of the utmost importance, as it is the first few seconds that count in dealing with a fire. On the other hand, the portable apparatus can be brought into use to aid the action of the fixed apparatus, and generally should be capable of the greater discrimination which can be obtained by the introduction of the human element, provided the personnel have received a very careful training. Portable apparatus should be especially useful in instances where scattered fires have commenced outside the area controlled by the fixed equipment or remained in the area after the discharge of the media.

Considering the various media which may be employed for fire-fighting, when gases are used a difficulty which may arise is to ensure that the burning material is completely enveloped without interfering with the actions of the personnel. Instances of this are to be found in cable fires in tunnels, confined cable basements and switch galleries, where access would be delayed until the gases had been cleared. Also it should be remembered that fires have often been preceded by explosions sufficiently violent in character to wreck the necessary barriers and screens, so that the protection afforded the gases against draughts might be seriously affected and the efficiency of the media impaired.

The partial destruction of the fixed type of apparatus using any of the available media can be envisaged, and the provision of auxiliary portable apparatus is therefore desirable in positions where the personnel are available.

Col. C. S. Lyon: After reading through Sections (1) to (10) of the paper, I was prepared, in view of the results tabulated, to find that the use of water as an extinguishing medium was not going to be included in the Recommendations. I am sure that had there been used some firing material other than cotton-waste wads, the results would have been substantially different in certain of the tests. It is generally recognized in the fire service that raw cotton, cotton wool, cotton waste, hessian, etc., is not easily extinguished in bulk. The quantities of these materials used in the tests described, or the quantities likely to be negligently left lying about in a power station, must, however, be so small that the extinguishment of them would no doubt be rapid under strong water discharge. It seems to be possible to say that, in the course of the tests, the water had not access to these materials, for some reason undisclosed: this issue is important since projectors should be provided to give water discharge over the whole of the risk. The hazard of extinguishing cotton waste is not a normal adjunct to an electrical fire, and while in these tests toxic gases may have appeared to deal more expeditiously with such foreign materials hidden away amongst electrical apparatus, it does not follow that, in practice, gases would be more effective than water properly projected.

In the second paragraph of Section (10), reference is made to the necessity for taking steps to prevent rags and combustible material from being left in nooks and crannies of electrical equipment. To my mind the question of extinguishing such rags once fire has broken out is a minor matter. The vital point to be realized is that such rags—and waste—are often the *cause* of the fire, as there is nothing much more sure than the ultimate spontaneous ignition of this type of combustible material, which is normally oily when thrown away by workmen.

It is significant that when water was provided by manual application, i.e. by a fire brigade, the quantity of water used far exceeded that used by the automatic sprinkler system. I was surprised, in spite of frequent first-hand experience of the efficiency of sprinkler installations, at the comparatively small amount of water released by the sprinklers during the tests.

An explosion frequently precedes or accompanies the conflagration of electrical apparatus. Such explosion usually disrupts the building (when one is involved), blowing out doors and windows, and drawing in a big volume of air which fans and feeds the flames, and causes through-draughts which will go far to defeat any gas-extinguishing installation. On the other hand, such explosions would bring in a sprinkler curtain even before the actual fire reached some of the heads.* Moreover, the cooling effect of water is one of the principal arguments in favour of its use for extinguishing purposes at an electrical fire, now that it has been proved that by using finely divided sprays there is little danger to those handling branches from a hydrant or fire engine.

Questions other than those appertaining to actual extinguishing, however, must enter into considerations regarding the most effective extinguishing apparatus. Inert or toxic gases by their very composition are effective because they exclude oxygen from the fire, or from the room in which it breaks out. They can only be thoroughly effective if it can be guaranteed that during the course of the fire nothing will happen to allow additional air to get to it. Assuming that this somewhat difficult condition can be fulfilled, then we are liable to arrive at a situation where the spark of human life in close contact with the fire would not be encouraged any more than the fire. In fact, human life would probably be extinguished before the fire was put out. Herein lies the crux of the selection of an automatic or other extinguishing apparatus, because it is seldom that the automatic apparatus completes without human aid the extinction of a fire. It must therefore be realized that, whatever the extinguishing medium, a human being must be present at some time during the fire. Firemen called in to premises equipped with gaseous extinguishers cannot know how much gas has been released before their arrival. I do not consider that in practice the conclusions regarding methyl bromide (page 733) are fully borne out, and it is dangerous to suggest that the gaseous medium which extinguishes a fire in the shortest time offers the least risk of injury to personnel, because every fire produces a different extinguishing problem and vastly varying conditions for the fire-fighters.

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* Full information on the intensity of these explosions may be culled from H.M. Stationery Office publications dealing with electrical accidents.

As regards the relative dangers of CO_2, methyl bromide and carbon tetrachloride, the first-named is the least dangerous toxically as far as extinguishing apparatus is concerned, but it would appear to have other dangers. For example, a serious explosion took place when a fire was being extinguished with CO_2 at the Detroit Fire Department Drill School on the 31st July, 1935, at a demonstration which was being given before the fire officers from all over the U.S.A. The test room measured 10 ft. 10 in. wide by 13 ft. 5 in. high by 15 ft. long; 1 quart of gasoline was lighted in a metal tray placed in the middle of the room; the tray measured 2 ft. by 3 ft. by 2½ in. deep. Two 50-lb. cylinders of CO_2 were connected to discharge outlets mounted on the side walls at a height of 2 ft. 10 in. and projecting downward in the direction of the tray at an angle of 45°. About 1 min. after the petrol had been lighted, the CO_2 apparatus functioned, and ¾ min. later there was an explosion which blew out the doors and windows. Forty of the observers, who were watching the demonstration through the windows, were taken to hospital and one later died from his injuries. Later, under safe conditions, the demonstration was repeated and another explosion occurred. I doubt very much if these explosions would have taken place had the extinguishing medium been water applied in a fine spray.

I should have liked to see another column added to each of the Tables in the paper, after the column headed "quantity of medium discharged," such column being headed "cost of medium discharged." The information contained therein would be read in conjunction with some details regarding the cost of (*a*) supplying and erecting the extinguishing apparatus under test, and (*b*) cleaning-up after each test.

I should like to endorse the recommendation to provide a minimum running pressure at the nozzles of 50 lb. per sq. in., since such pressure will ensure emulsification of the oil and certainty of extinguishment under all conditions. The summing-up of the properties of foam would appear to indicate a more comprehensive experience in its use than could have been obtained from the tests dealt with in the paper. I was especially interested in the remarks about smoke-detector apparatus, having been privileged to witness one of the earliest demonstrations of that invention. To me it has two disadvantages for general use, viz. delicate mechanism and the liability to false alarm if anyone has a quiet smoke in a still quieter corner!

One point has been omitted from the reference in the paper to dwarf walls. Such walls should be of sufficient height and be so placed with regard to the electrical equipment they surround that in no circumstances can oil be projected outside the walls however the apparatus may burst open as the result of electrical action. In addition, it is desirable that the enclosure formed by the dwarf walls should be drained to a sump or other discharge point, through a flame trap, and the drain should have sufficient capacity to carry away all the water discharged into the area.

The Fire Offices' Committee, after much experience of the types of installations mentioned on page 733, has framed a comprehensive set of regulations with which compliance is obligatory if insurance rebates are to be obtained. It therefore follows that these regulations might be advantageously carried out even where the question of a reduction of insurance premiums does not arise.

Recent weather conditions have demonstrated all over the country the advantages of being able to change over from wet to dry, and have exposed the disadvantages of the purely wet fire-fighting system. The stress laid by some engineers on the damage done by water to electrical apparatus is due to their having seen the results of extinguishing by water manually applied, and frequently not confined to the seat of the fire. The automatic sprinkler is much more local in its action, and in my experience only does a lot of water damage when the alarm bell has rung for some time without being heard. The installation may with advantage be coupled to an electrical device actuating a remote alarm in the works or fire-brigade watch room, as was done in 1936 by request of the Liverpool Salvage Corps at a group of tobacco warehouses. This additional precaution precludes the possibility of unnecessary water damage without in any way interfering with the efficacy of the sprinkler system.

Mr. R. E. Eberhardie: With automatic CO_2 installations a portable standby is advisable, not because failure of the installed system is to be anticipated, but as a means of quenching small fires and thus eliminating the necessity for the discharge of the main system.

Mr. Morland mentioned that fire brigades have frequently been called upon to deal with fires which have originated in an explosion. It is reasonable to suppose that an explosion of sufficient violence to cause a fire will also be sufficiently violent to displace the discharge nozzles of the water or foam protective systems and thus seriously reduce the efficiency of the system. With a gas system of protection, however, owing to the rapid expansion of the gas, the displacement of a nozzle will not have the same serious consequences.

I should like to draw attention to the need for accuracy in the test reports of fire-fighting equipment. It is a pity that the actual time of extinction in each case is not given for the CO_2 tests described in the paper; for this time factor is a matter of importance in correctly assessing the efficiency of the system and the amount of gas actually necessary for extinction. In Table 4, Test No. 16, the discharge period is given as 27 sec. and the quantity of gas discharged as 100 lb. In point of fact, although the cylinder capacity was 100 lb. of liquid CO_2 the amount of gas actually discharged in 27 sec. was approximately 30 lb.

I do not agree with the statement (page 733) that the medium which extinguishes the fire in the shortest time offers the least risk of injury to personnel. This time-period comparison could only hold good provided the two gases compared were identical in both their chemical and physical properties, and they had not the same properties. Carbon dioxide is non-toxic, no matter what its concentration. As the deduction stands, it is analogous to comparing the toxic effects on a human being of a glass of water and of a glass of poison. There can be no time-period comparison of toxic effect between two substances, one of which is toxic and the other non-toxic.

[**Mr. H. Hoyle** also took part in the discussion. The substance of his remarks will be found in the report of the Birmingham discussion (see page 266.]

[The reply of Messrs. J. Hacking and R. A. McMahon to this discussion will be found on page 276.]

NORTH-EASTERN CENTRE, AT NEWCASTLE, 12TH FEBRUARY, 1940

Mr. J. Kennedy: I consider that electrical fires should be tackled at their source by electrical isolation, and that the fire-fighting installation should be designed to take care of those faults or occurrences which are beyond the control of the electrical engineer.

Mr. R. E. Eberhardie: I should like to emphasize the necessity of having all fire equipment regularly inspected. Most firms supplying fire equipment are themselves prepared to carry out the periodical inspection of equipment supplied, or to train some of the staff to do so.

It would be interesting to know what is the cost of the back-up equipment required in connection with the various types of water-spray protection.

In time of war an outbreak of fire due to enemy action cannot be anticipated, and adequate protection must be provided to deal with it immediately it occurs.

The films which have been shown indicate that after a number of the tests a little flickering flame was left, and I would mention that this could not be extinguished except by means of CO_2. A gas, which expands in all directions, has a far greater possibility of reaching flames in nooks which are inaccessible to water.

Oily rags and waste left about in the neighbourhood of transformers and other electrical apparatus are not only potential sources of fire but may be responsible for re-ignition. This menace could be corrected by making one individual personally responsible for the cleanliness of the apparatus.

Mr. H. Leyburn: Ever since the occurrence of the fires mentioned in the Introduction, I have had the feeling that if only as much time and energy had been spent on fire-prevention as has been spent on fire-fighting the bogy of destructive fires in power stations could have been eliminated. It must be remembered that these fires were due to breakdowns of unprotected power-station switchgear, i.e. of apparatus in which a fault, once it had started, could not clear itself in a reasonable time. This condition, which until recently applied to practically all power-station switchgear, is in direct contrast with conditions in all other electrical apparatus, which is fitted as a matter of course with automatic protective gear so that it may be disconnected either instantaneously or after only a short time-lag as soon as a fault occurs. If in what follows I deal almost exclusively with the prevention and fighting of fires in power-station switchgear, I do so only because this most important part of the power supply system has not been dealt with satisfactorily in the past as regards fire-prevention, and in this way what might best be described as unwarranted fire consciousness has been created quite unnecessarily.

There is little doubt that the comparative freedom of electric supply networks from fires and other serious troubles in the past has been due to the fact that the apparatus was protected by fast-acting protective systems. Equally, there is no doubt that, irrespective of the materials used for switchgear construction, sustained uncontrolled arcing rendered possible by the absence of such protective systems from busbar zones in power stations has been the primary cause of the fires and other troubles that have occurred there.

It has been proved by a large number of tests and confirmed by actual breakdowns on site that time is essential in starting an oil fire. It may be said with a high degree of certainty that, with earth-fault currents of the magnitude common in modern supply networks, a breakdown in oil that is isolated in less than 1 sec. will not give rise to a fire; if the uncontrolled arcing is allowed to persist for, say, from 1 to 3 sec. there is a slight chance only of a fire occurring; if, however, it is allowed to persist in excess of 3 sec. the chances are increased considerably—roughly in proportion to its duration. It follows, therefore, that by avoiding sustained uncontrolled arcing in oil, i.e. by isolating faults automatically in a short time, fires can be avoided.

As it happens, however, the quick isolation of a fault is required not only in order to avoid fires but also to enable fire-fighting appliances to be used at all. In this connection the authors make the following brief but important statement:* "Whatever type of fire-fighting installation be provided, whether fixed or portable, automatic or hand-operated, it is essential that adequate provision should be made for isolating electrical equipment affected by the fire as quickly as possible. . . ." I contend that such provision must not rely on manual operation of the switchgear, which requires great presence of mind on the part of the attendant and leads to loss of valuable time, but that it must be entirely automatic. A case occurred a few years ago at Brimsdown where, the control wiring having become damaged owing to unavoidable delay in tripping the circuit-breakers, it was found impossible to isolate the affected switchgear. As a result, fire-fighting apparatus was of little use, and the fire-brigade was unable to fight the fire until a considerable time after it had broken out. Such a condition could have been avoided only by the provision of instantaneous busbar-zone protection capable of isolating the faulty switchgear before the control wiring was damaged.

Another important point often overlooked is that to isolate switchgear it is necessary to trip not only the local circuit-breakers but also circuit-breakers at the remote end of feeders capable of feeding fault power back into the affected switchgear. This makes it still more important to provide automatic busbar-zone protection in order to ensure the isolation of the affected electrical equipment.

Once busbar-zone protection has been applied, however, the root cause of electrical fires, namely sustained uncontrolled arcing, is absent, and the chances that a fire may occur and the fire-fighting appliances may be required at all become very remote indeed. Judging from the circumstances of previous occurrences and from tests made since then, it is not too optimistic to estimate that 95 per cent of all switchgear fires at power stations could be avoided merely by the provision of instantaneous busbar-zone protection.

I may appear to have laboured the question of the instantaneous isolation of faulty power-station switchgear, but I consider that it is all-important not only from the point of view of fire prevention but also in relation to the choice of fire-fighting appliances. If, as has happened in the past, it had to be assumed that almost every breakdown of power-station switchgear was likely to give rise to a serious fire, the measures it was necessary to take had obviously to be very stringent indeed. If, on the other hand, the likelihood of a fire can be made almost negligible by the provision of instantaneous protective equipment, the problem of providing fire-fighting appliances assumes an entirely different aspect both economically and technically. However carefully fire-fighting appliances are installed, there is always a danger that the extinguishing medium may be released inadvertently, and this has to be balanced against the probable number of times it will be used for actually putting out a fire. With this consideration in mind, provided that the expectation of fires is reduced to negligible proportions by the use of instantaneous protective equipment, I consider that for indoor gear an inert gas such as CO_2 is preferable to a fixed water-sprinkler installation, even though it may be less effective. The inadvertent release of water may damage healthy indoor gear, whereas CO_2 cannot have any such effect. There is no objection to the use of water-sprinklers for outdoor gear.

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* See *Journal I.E.E.*, 1939, **85**, p. 733.

The authors recommend that efficient back-up (fire-fighting) protection in the form of outside hydrants should be provided. I suggest that they should be made the first line of fire-fighting defence. In addition, when the chances of a fire have been reduced to negligible proportions by the provision of instantaneous protection for all apparatus, including power-station switchgear, fixed fire-fighting equipment in the form of CO_2 (for indoor gear) and of water-sprinklers (for outdoor gear) should be installed only as an additional safeguard if the responsible engineer feels that it is economically justifiable.

I have not yet touched upon fires that may be due to causes other than electrical breakdowns leading to uncontrolled sustained arcing; for example, to incendiary and high-explosive bombs. Here again the suggestions I have made above would be quite satisfactory in that the instantaneous protective gear would isolate the affected apparatus as quickly as possible and outside hydrants would be available for fighting any fire that might occur. If fixed fire-fighting equipment were also installed it could not always be relied upon, because it might be damaged by the bomb explosion that started the fire; alternatively, the extinguishing medium might be released by an explosion that did not in any way involve the gear with which the fire-fighting equipment was associated, and, if it were water, otherwise sound gear might be damaged.

To summarize, my views concerning the prevention and fighting of serious fires, such as have occurred recently in power stations, are as follows:

(1) Instantaneous protection should be provided for all apparatus in power stations. The main switchgear, hitherto neglected in this respect, should have fitted to it instantaneous busbar-zone protection. By avoiding sustained uncontrolled arcing, these measures, which incidentally are now being almost universally applied, will no doubt eliminate practically all serious fires.

(2) The very few fires that may still occur in spite of (1) above should be dealt with mainly by outside hydrants, in the use of which the power-station personnel should be drilled occasionally.

(3) If, in addition, fixed fire-fighting appliances are thought to be economically justifiable, they should be such that the extinguishing medium will not damage the protected gear if it is released inadvertently; for example, for indoor power-station switchgear it is preferable to use CO_2 although this may be less effective than water from the point of view of fire-extinction.

Mr. R. J. Mowle: I note with regret that no mention is made in the paper of the importance of emulsification as a means of ensuring positive and rapid extinction of burning liquids. In dealing with water systems the paper states "In no case should the running pressure fall below 50 lb. per sq. in. at the highest nozzle when all the nozzles are open." Undoubtedly emulsification would take place if this recommendation were carried out.

With a water system of the emulsifying type, water is discharged from the projectors (or nozzles) in the form of powerful broken streams which, on impact with the surface of the oil, break it up into an emulsion of the "oil in water" type. Such an emulsion when examined under a microscope is seen to consist of minute globules of oil, each surrounded by a film of water. Thus the inflammable liquid is converted into one which will not burn, and the risk of "flash-back" or re-ignition is removed. Water should not, however, be sprayed on indiscriminately, for without emulsification water cannot be relied upon to extinguish such fires under all conditions.

Mr. D. H. Chisholm: I am interested in Tests 41–44 using atomized water, in which the extinguishing times were $6\frac{2}{5}$, 7, $9\frac{1}{2}$ and 27 sec. respectively. These times do not agree with the figures given in the paper for Tests 42 and 43, in which the extinguishing installation was allowed to run after the oil fires had been extinguished in order to see whether the firing wads also would be extinguished. In only one case did the protective installation fail to extinguish these wads.

My company set out 5 years ago to design a system which would permit of the use of low water pressures, because it was felt that the high-pressure system was unnecessarily expensive. The extinguishing system employed in Test 41–44 was designed for operation at 30 lb. per sq. in., and we were under the impression that this pressure was available from the town mains at Barking. It was found, however, after installing a small portable pump drawing the water supply through hose lines, that a pressure of 16 lb. per sq. in. was the greatest available at the projectors. Nevertheless, we decided to proceed with the tests, despite the fact that we were utilizing some of the margin of safety which had been allowed in designing the system for 30 lb. per sq. in. The performance of this installation was satisfactory on every occasion, and therefore we do not understand the need for the statement on page 733 that the running pressure at the projectors should not be less than 50 lb. per sq. in. (Mr. Chisholm concluded by showing a cinema film of the development work in connection with this system.)

Mr. R. J. Bellerby: North-East Coast engineers have been seriously concerned since October, 1925, with the possibility of fires in electrical power stations and substations, but even before that date a fair amount of attention was being paid to what may be called first-aid appliances. It was realized that the risk of fire was being increased by the use of higher voltages, and the increasing size of turbo-generators, transformers and switches, in all of which oil was being used in increasing quantities and fault currents were larger.

A test of a system of extinguishing fires by means of CO_2 released from cylinders was made in July, 1926, 12 years prior to the experiments described in this paper. As a result of this experiment the CO_2 system was adopted for certain of our switch-houses.

In October, 1934, Pyrene air-foam tests carried out at Billingham were witnessed by ourselves and representatives of several fire brigades, with the result that the necessary apparatus was obtained and experiments made with it at North Tees power station. These experiments give very satisfactory results.

In September, 1935, the use of methyl bromide as an extinguishing agent was brought to our notice, and tests were made comparing it with carbon-tetrachloride and chemical-foam hand apparatus. In November of the same year it was decided that in future methyl bromide should be used in preference to carbon tetrachloride, since it was quicker in action and the gases formed in use caused less distress to the user.

In October, 1935, just before the introduction of methyl bromide into our stations and substations, a series of tests were witnessed of the Mulsifyre fixed installation water-spray system, and we also conducted experiments of our own with this system. It is now used to deal with certain transformer risks in our power stations for which it is considered suitable.

In April, 1936, another form of fire protection was tested, namely asbestos-covered steel girders. The test was successful, and where considered necessary these girders are now being used.

The European situation then began to affect our ideas. The possibility of war, with high-explosive and incendiary bombs dropped from aeroplanes, made the necessity of being prepared for fire more important than ever. It was deemed necessary to obtain more knowledge regarding actual fires; to this end, in 1937 our imitation transformer fire was built, and the same year an imitation of a burst turbine oil pipe was constructed. This apparatus has been used for tests and the training of fire squads.

War conditions as they were visualized in June, 1937, might easily mean that the town-main pressure, even though the mains remained intact, would be so low due to several fires being fought at the same time that even a professional brigade would be very seriously handicapped by shortage of water. This thought led to the installation at strategic points in our power stations and main substations of auxiliary portable petrol-driven fire pumps, the provision of easy access to the rivers near the power stations, the utilization of tanks for reserve water supplies, and the provision of sunk water-tanks and engine-pits for our main substations—for protection against high-explosive blast and splinters and to some extent against frost.

In Section (11) (*a*) it is stated: "Considerations of this nature are entirely dependent upon local conditions covering a wide range of factors, and upon this point each case should be considered on its merits." Again, from the Recommendations in Section (12)A it is evident that local conditions must play a great part in the choice of medium to be used, so much so that for all four classes of risks either atomized water spray, inert gas, or foam can be used so long as they are applied properly. Would it not, therefore, have been simpler to say: Study the local conditions and, whichever medium is considered suitable, see that it is properly applied?

Fixed fire-fighting installations are useful pieces of apparatus, but most engineers will agree that absolute reliance must not be placed on them as a means of stopping a fire. Further, they cannot very well be installed to cover all the space requiring protection. So we must have various types of portable apparatus, from small hand appliances to those requiring at least two men to handle. The following, which are sometimes referred to as "first-aid appliances," are in use: (*a*) acid-alkali extinguishers; (*b*) foam extinguishers; (*c*) carbon-tetrachloride extinguishers; (*d*) methyl-bromide extinguishers; (*e*) hand stirrup-pumps; (*f*) foam branch pipes. These small appliances, like the larger ones, have to be regularly inspected and tested. In July, 1939, a pamphlet was issued to all persons responsible for and likely to direct the use of fire-fighting apparatus, giving our experience in keeping small appliances in order and ready for fire.

As regards back-up appliances, we agree with the Recommendations in suggesting that water-hydrant protection should be provided if possible. We have provided portable petrol-driven pumps drawing their water from rivers or storage tanks (the tanks hold an hour's supply of water). Sufficient foam compound is provided for at least half-an-hour's run, leaving the rest of the water for cooling-off purposes.

During the London discussion on this paper Mr. Nimmo laid stress on the necessity of having personnel properly trained in the use of fire-fighting appliances, and in this connection I would say that once a week at our main stations men receive instruction and drill from a professional fire-brigade officer, and once a month squad leaders and sub-leaders from outlying districts receive training with them.

Success in fighting a fire depends upon attacking it quickly (hence the need for constant drilling) and from a point as near to it as possible. Regarding this latter point, we have devised a 2-wheel truck which carries a shield and will if necessary hold a foam-making branch pipe and knapsack. It allows the branch pipe to be directed in any forward direction or fixed at will. It is intended to make the use of a hose and branch pipe more easy when the number of men available is small.

I should like to mention a test which was made with an oil-cooled transformer having artificially short-circuited turns in its windings. It was made alive and the oil raised to boiling point by heat developed at the fault, and, although the oil was kept boiling for some time, no fire was started. Eventually the transformer was set on fire by means of ignited rags applied to the open top of the tank. Very quickly a fierce fire was burning because of oil on the floor which had boiled over and of oil and paraffin which had been put there on purpose. It was put out in a few seconds by hand-operated Mulsifyre water jets with which the chamber had been fitted. It would appear from this experiment that submerged short-circuited turns are not likely to start a fire until the oil has been boiled away sufficiently to expose or nearly expose the faulty place. In such a case as this a Buchholz relay or a temperature-operated alarm would give ample warning of the transformer's condition long before a fire could start.

Mr. W. S. Coates: The tests described in the paper which were carried out without automatic equipment would appear to have been too hurried. We generally allow a longer period than 2½ minutes or so for the fire to get well away. Fire-fighting squads which are drawn from substation personnel do not get the daily practice of the local authority's fire-brigade personnel, hence more than 2½ minutes may elapse before the main fire-fighting equipment is in operation. There is no doubt that the longer the fire is allowed to burn in order to heat thoroughly the surroundings, the more difficult it is to extinguish.

The paper specifically mentions the toxic properties of carbon tetrachloride, methyl bromide and carbon dioxide; but it does not appear to be generally realized that highly toxic substances (such as carbon monoxide, acrolein, etc.) are also produced during uncontrolled combustion of hydrocarbons, and some of these substances are lethal. We have provided Salvus oxygen breathing apparatus to enable operators to enter any irrespirable atmosphere such as exists during a fire or immediately after one has been extinguished. We suggest that attention could be usefully drawn to this type of apparatus, and that the grave dangers of the indiscriminate use of smoke helmets should be clearly pointed out.

Our experience shows it to be highly desirable to inaugurate a systematic inspection of all fire-fighting equipment, as already suggested by Mr. Bellerby. This comprises hydraulic pressure testing up to 350 lb. per sq. in. of all extinguisher bodies which are subjected to pressure during operation, but which are not normally under pressure, and the testing of solutions and their replacement when they are below a predetermined standard. All volatile-liquid extinguishers are frequently weighed, and the operating mechanism examined. All CO_2 cylinders are weighed at regular intervals, and the remote-controlled mechanisms brought into operation. All fire pumps, hydrants and auxiliary equipment are frequently operated to ensure satisfactory condition, and to give practice to the squads.

I should like to ask whether the E.R.A. consulted with the Fire Offices Committee before carrying out their tests and whether the Committee approve of the various types of extinguishers which were used in the test.

Finally, it is suggested that the E.R.A. could usefully devote time to the investigation of non-inflammable liquids for dielectrics in place of hydrocarbons, such as the chlorinated naphthalenes. It would be of interest to know whether such an investigation is likely to be included in a future programme.

Mr. M. Chadwick: I am pleased to see that the paper advocates the use of protecting concrete walls surrounding oil-cooled switchgear and transformers. This not only helps to keep the fire confined but also affords the fireman a good deal of protection in his approach.

With reference to the use of carbon dioxide, methyl bromide and carbon tetrachloride, on all the occasions when I have tried these compounds—usually in confined atmospheres—it has been vitally necessary to employ oxygen breathing sets in carrying out an inspection in order to ascertain how the apparatus has dealt with the fire. The heavy gases produced by the use of these extinguishing media can hardly be described as lethal, but the most important point to remember is that the gas excludes or drives out the air from the vicinity of the outbreak. In an atmosphere which is thus deficient in oxygen, personnel not suitably protected may collapse from asphyxiation.

The paper contains frequent references to the different qualities of foam used in the various experiments; I should have thought it would have been possible to vary the density of the foam during application. With the Pyrene-foam branch pipe this can be done by adjusting the small control valve feeding the compound or by reducing the water pressure.

Regarding the part played by atomized spray, in watching a demonstration given some time ago I was surprised by the effect of such a spray of water upon the surface of blazing oil. Fixed installations of this type appear to be highly satisfactory. It would be interesting to know whether, instead of using ordinary water, a solution of bicarbonate of soda might help to produce this effect.

Fire officers find that CO_2 is only reliable in confined atmospheres; and we have always considered that 6-in. fire mains are the absolute minimum for installations in power stations.

At a switchgear fire which occurred at the Brimsdown power station some arcing occurred across the contacts of one of the banks of switches and the engineers were unable to break contact, the remote-control wires having been put out of action by the outbreak. The fire developed very quickly and flaming jets of oil were thrown some considerable distance, involving other switchgear. One of the North London fire brigades was called, and upon arrival the chief officer was informed by the power-station electrical engineer that the switchgear was still alive and the voltage about 33 000 volts. It was emphasized that it was impossible to approach anywhere near the switchgear to isolate it. As the fire was developing at a rapid rate the risk was taken of fighting it by means of foam and Mulsifyre jets, and control was gradually obtained by this method.

It has been stated that statistics show that a fire occurs in a power station on the average only once every 112 years. Nevertheless, fire protection arrangements in power stations are vitally necessary, and the risk of power-station fires is sufficiently large to warrant expensive precautions. Even if perfection had been attained in switchgear, we should still have to face the problem of hostilities, which can and may produce entirely unforeseen circumstances.

[The reply of Messrs. J. Hacking and R. A. McMahon to this discussion will be found on page 276.]

NORTH MIDLAND CENTRE, AT LEEDS, 9TH MARCH, 1940

Mr. W. Dundas: The first point I would stress is the necessity for having equipment that will function automatically. I do not suggest, however, that portable equipment should be ruled out altogether, as such appliances are of value and serve very useful purposes.

The films illustrating the E.R.A. tests are mostly concerned with transformers, which in general are not subject to serious fire risks. Where a transformer is located out of doors and well away from other plant there does not seem to be the same necessity for fire protection as with indoor transformers, where protection is desirable and in some cases essential.

With regard to cables, the risk of ignition due to a fault or to the limit of thermal capacity having been exceeded appears somewhat remote, although the latter cause cannot be ruled out entirely, especially where the smaller cables are concerned. In the Bradford fire, extensive damage occurred to the h.v. lead-sheathed paper-insulated cables in the switch-house basement owing to contact with burning oil which had penetrated into the basement. It was some time before the fire could be located, owing to the dense smoke. It is evident that, once the lead had melted, the insulation burned fiercely and the fire spread with alarming rapidity, leaving nothing but the bare copper with its supporting steelwork in position and molten lead on the floor. The situation was rendered much more difficult as the multicore wire-armoured cable shared the same fate.

A good deal of thought has since been given to the protection of cables in basements, and in some instances a covering of non-inflammable lagging has been used; but as such a covering affects the thermal resistance its application is somewhat limited. In my opinion, the best method for protecting cables is the ordinary sprinkler system.

An important point that must not be overlooked in cable layouts is the provision of effective sealing where the cables pass through walls and floors. This matter was fully dealt with by Mr. Siviour in his Chairman's Address* to this Centre.

Referring to the protection of switchgear, experience has shown that water is a very undesirable fire-fighting agent, even for use on metalclad gear, and cannot be employed indiscriminately. If used, it should be confined to the lower portion, i.e. the parts under the switch tanks, where it would effectively deal with any burning oil that might be ejected from a switch tank, without coming into contact with the metal parts of the gear. The alternative is to provide suitable drainage arrangements under the switch tanks. Although it would appear almost impossible that water could penetrate into metalclad busbars, I know of a case where this actually happened, and many anxious weeks were spent before the opportune moment arrived when the busbar chambers could be taken out of service for reconditioning.

From the above remarks it will be gathered that I favour the CO_2 method for switchgear protection, together with a system of drainage.

I would draw attention to the importance of systematic and regular maintenance of fire-fighting installations, which, having to remain inoperative over long periods of time, must receive careful attention in order to ensure that they will function at the critical moment. So far as water systems are concerned it is necessary to take precautions against frost, a danger which was particularly evident during the severe weather experienced in the early part of this year.

Mr. J. Kennedy: Dealing with the question of the maintenance of fire-fighting equipment, I would mention that all firms supplying automatic fire-extinguishing gear carry out regular inspections of installations made, and are only too pleased to test fusible links, sprinkler heads, etc., in order to satisfy the engineer in charge that the gear will operate satisfactorily.

Where a fire-protection system of any considerable size is being installed it must be of the automatic type if it is to be really satisfactory. However prompt the warning, so much damage may be done before hand-controlled gear can be brought into use that in the result the plant may be as effectively shut down as by a complete burn-out.

Smoke detection is one very effective answer to the cable fires mentioned by Mr. Dundas. At the Barking tests we used a unit which was so effective that it was impossible to light the test fire without bringing the alarm into action. I do not favour smoke-detection control of fire-extinguishing gear, because of the danger that a fitter, for example, may smoke or use his blowlamp near the detector; but the detection system is available and it will give early warning. With cable fires a lot of smoke is usually given off before anything serious happens.

Mr. Dundas also mentioned water protection of cables, and there is undoubtedly a lot to be said for this type of protection for cables, as there is generally a large reserve of water available. Water has the disadvantage, however, that it will get in where it is least wanted—one must be guided by the layout when considering installation. During the tests, whereas burning firing-wads shielded from water continued to burn after the main fire had gone out, the methyl-bromide system promptly extinguished them in every case; and I have heard the representatives of companies which manufacture CO_2 apparatus say the same of their gear.

The question of physical isolation is probably half the problem, and I do think that the fire-protection gear should be auxiliary, to take care of "Acts of God and the King's enemies," rather than to obviate the necessity for careful layout of the gear.

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* *Journal I.E.E.*, 1937, **80**, p. 30.

Mr. R. M. Longman: The effect of prevailing winds on the fires shown in the E.R.A. film was very noticeable, and the building of fire walls round the transformers or switchgear would reduce this effect considerably. The films stress the importance of ensuring that no pieces of waste, cloth or rag are left near any transformers, switchgear or other oil-filled apparatus.

I should like to mention a case where a fire broke out on a large transformer and the fire brigade arrived 20 minutes after the outbreak; although a large quantity of burning oil spread over the ground (large stone with chippings on the surface) no difficulty was experienced in putting this fire out.

I wish to confirm that the makers of fire-fighting equipment are only too anxious to carry out regular maintenance and tests of such gear in conjunction with the owners.

It may be asked why the Central Board have not installed automatic fire protection on all their transformers. The answer is that the Board's methods of electrical protection, leakage system, Buchholz relays, etc., ensure the switching-out of transformers so rapidly as to minimize greatly the chances of fire; and in addition fire walls are provided to localize any fire which might occur.

A type of fire risk in power stations which is not dealt with in the paper is the risk due to hot oil escaping and impinging on steam pipes or hot-air ducts. Notable instances of this were the fires at Brussels power station, in which the roof caught fire and the station was gutted, and, more recently, one at Portishead. The common ingredient is oil: how can we eliminate it?

Prof. E. L. E. Wheatcroft: Metalclad gear is particularly liable to damage by a fire, which may, of course, not be started in the gear itself; and since, in most cases, the gear is filled with compound or oil, there is little possibility of saving the particular piece of apparatus which catches fire. The main object, therefore, of the extinguishing apparatus will be to confine the fire to one particular piece or section of the equipment. It follows that just as important as, or more important than, the fire-fighting equipment itself is the question of layout from the point of view of segregation. Particularly does this seem to be so in view of the conclusion in the paper that all the types of fire-fighting equipment which were tried had equal merits from the point of view of putting out the fire. I therefore want to stress my view that a carefully planned layout with segregation of the damage as its object ought to be the first thought of the engineer, and that every effort in this respect would be worth while if it would prevent complete shutdowns, such as have been experienced in various major power stations in recent years.

The other point which seemed to me of importance is that of supervision and maintenance. This is a problem which applies to all equipment which is not in regular use but is wanted very badly indeed and required to be immediately effective when occasion arises. It should be the duty of the supply engineer to make sure that his fire-fighting apparatus will be in working condition when the occasion arises for its use, and this applies not merely to the detector gear but to the whole system.

[**Mr. H. Hoyle** also took part in the discussion. The substance of his remarks will be found in the report of the Birmingham discussion (see page 266).]

[The reply of Messrs. J. Hacking and R. A. McMahon to this discussion will be found on page 276.]

SOUTH MIDLAND CENTRE, AT BIRMINGHAM, 1ST APRIL, 1940

Mr. E. A. Newburn: Just after the Bradford fire I had to design a fire-fighting installation for a new important switch-house receiving a bulk supply. I decided on a gas installation, principally because the apparatus to be protected was capable of being sectionalized and placed in relatively gastight compartments. Water or foam was ruled out, first because of the risk of damage to gear not actually involved in the fire, and secondly because of the need to resume supply as soon as possible after a fire has been extinguished. Gas seemed to be very suitable because it produces little or no damage, and as it was an unattended switch-house (the doors of which could be closed) there was no danger to operatives.

The results of the tests given in the paper confirm the makers' contention that methyl bromide is a more effective gas than CO_2. I installed a CO_2 system as I understood there might be some danger to operatives who happened to be near the scene of the fire if methyl bromide was used, and that there had been some cases of collapse 1 or 2 hours afterwards. Were such effects observed after any of the tests made by the E.R.A.?

With regard to the risk of fire in cable basements or subways, to install an automatic fire-fighting equipment seems to me to be a very elaborate method of dealing with possible fires and one which, judging by the results given in the paper, is of doubtful efficiency. The correct way to tackle the problem would appear to be to design the installation so that it will not in itself maintain a fire.

In the installation which I planned each cable comes into a basement on a concrete rack and is filled over with 2–3 in. of sand. As provision has been made for the oil in the switchgear above to be drawn off in the event of fire by a pebble-filled trench system, and all cable holes are plugged, there is little risk of oil getting on to the cables below. If, however, by some mischance this should happen, the cables will be protected by the sand. As I think there is practically no danger of damage to cables, I have not thought it necessary to extend the protection to the basement. An elaborate system like that shown as necessary in the E.R.A. film would have been considerably more expensive and would in a confined situation have been difficult to install.

Mr. D. Kingsbury: With reference to the Bradford fire, I would point out that while failure of insulation on the switchgear was the primary cause of the trouble, the fire would not have been so disastrous had it not been for the lack of segregation in the cable basement.

The question of the time taken to deal with a fault is now known to be of considerable importance. It has been shown by tests that if a fault can be removed in 0·5 sec. even oil in a damaged metalclad chamber will not catch fire, whereas if the fault is maintained for 5 sec. it will. This emphasizes the need for busbar-zone protection in connection with switchgear, since it is not difficult to arrange that faults on other parts of a switchboard come within the zone covered by the circuit protection. Great strides have been made in regard to busbar-zone protection of recent years, and the possibility of spurious operation, which would of course be very serious, can be regarded as very remote.

Sections of the film illustrating the E.R.A. experiments showed cables racked to a wall and subjected to flame. It would appear to be better to bury such cables, and it has been shown that when only a few inches below the surface of pebble-filled trenches they are quite safe.

Mr. H. Hoyle: I do not agree with the statement made in the paper that water extinguishes an oil fire by its cooling action. Under favourable conditions atomized water may be effective, but it cannot be relied upon to deal with oil fires of the fiercest intensity. The extinguishment of any oil fire can be achieved by the application of water in such a manner that on impact an emulsion of the oil-in-water type is formed. Oil does not burn; it is only the gas liberated from its surface which can do so in the presence of the oxygen of the atmosphere. It is for this reason that an oil-in-water emulsion is non-inflammable. Each tiny globule of oil is surrounded by a thin envelope of water through which gas cannot escape.

To achieve such a result in practice, water is discharged in the form of fine, broken streams travelling at high velocity, due to the discharge pressure at the nozzle, and evenly distributed over the commanded risk. When the water strikes the burning oil surface the impact causes the oil to separate into tiny globules, around each of which water forms a continuous screen. To extinguish the fire it is not necessary to emulsify all the oil involved. If a thin layer of emulsion is formed on the surface of the oil it is sufficient to prevent the egress of further gas to the atmosphere, and therefore combustion ceases.

The principle of emulsification applied to oil-fire extinguishment is a comparatively recent discovery, although emulsions of the oil-in-water type and water-in-oil type have long been known.

Mr. D. H. Chisholm: I should like to refer first to the theory of emulsification which has been put forward to explain the effectiveness of atomized-water systems. In a true emulsion, it depends on the relative proportion of the phases as to whether phase A is surrounded by phase B or B by A. In an emulsion of oil and water, the water phase must predominate if each drop of oil is to be surrounded by water in the manner described by the sponsors of emulsification—otherwise the reverse will be the case and each drop of water will be surrounded by a film of inflammable oil. How is this initial preponderance of the water phase to be established in burning oil?

My second point arises from the installation of atomized-water systems protecting indoor or outdoor transformer banks. When a transformer bank is protected by a single atomized-water system, arrangements are commonly made so that water would be applied automatically to the fired transformer only; but the electrical fire-alarm is normally fitted in the water supply feeding the entire transformer bank, so that selective fire indication is not obtained with regard to individual transformers. Would selective fire-alarms situated over each transformer be of benefit to power-station engineers, in giving them the earliest possible warning of the exact location of the fire and perhaps enabling them to isolate the affected gear immediately?

Mr. J. Kennedy: The film illustrating the E.R.A. experiments showed that a "boil-over" occurred on the transformer fire when a water fire-fighting system was applied. Such an effect does not occur with the so-called gas systems, for reasons which will be immediately apparent. An important question which arises in connection with the use of water for dealing with electrical fires is what is going to happen to the water which falls upon the gear. The majority of engineers are faced with the problem of gear which already exists and which cannot all be readily converted to the waterproof type.

It is sometimes stated that the gas systems have some difficulty in reaching the heart of a very hot fire. Methyl bromide, on the other hand, is ejected as a liquid and will penetrate to the heart of a very hot fire without any great difficulty.

I agree with Mr. Newburn that cables should be buried. The correct approach to the fire-fighting problem is to start from the main floor and eliminate the fire risk wherever possible, then deal with the risks that cannot be eliminated.

As regards the toxicity of methyl bromide, I was present at the Barking tests and I saw 12 or 15 men standing up to their necks in methyl-bromide vapour without any apparent discomfort, nor did they suffer any discomfort subsequently.

Mr. N. M. Hill: In many modern installations a pit is put underneath the transformer and filled with granite chippings. Does the author think this practice is effective? Will the oil go through the chippings quickly enough to minimize the fire if one occurs?

I saw transformers some years ago in America where a pipe was run through the drain cock, at the base of the transformer, to a drain outside so that in the event of a fire the oil could be run off by opening a stop-valve. This arrangement is obviously only useful if the operator can get there quickly enough. Is this method being used now, and is it found to be effective?

Mr. J. A. C. King: It is sometimes asserted that the application of a gas to a fierce fire is liable to be ineffective because the ascending currents and vapours due to the fire may overcome the tendency of a heavy gas to fall. Surely very much the same criticism could be applied to atomized water spray. It has to be provided in very large quantities before it will descend through the flames.

I should like to mention a question which arises where drainage sumps are provided, filled with granite chippings or similar material, and of such capacity that they will absorb all the oil in the transformer or other gear mounted above them. If a fire breaks out in an installation equipped in this way, and the firemen have to play a considerable quantity of water on to it, surely a good deal of the water will run down to the drainage sump and float out the oil, thus providing fuel from below as well as from above.

I believe some American supply authorities have conducted experiments in which jets of water were directed on to live high-voltage overhead transmission lines to find out what was the possibility of an electric current being conducted back down the jet, and it was discovered that it was quite safe for a man to hold a copper nozzle from which a 40-ft. jet was being thrown on to conductors at 132 kV. The theory was that the end of the jet was sufficiently broken into spray to prevent the current being transmitted back to the stream close to the nozzle.

I should like to know whether the introduction of inert gas into the transformer housing has been considered. It would surely rule out the risk of fire at or near the top of the oil in the tank.

Dr. W. Wilson: There are two methods of putting out a fire—to stifle it by excluding air, and to chill it by reducing the temperature of the burning gases below their ignition point. Water does both of these very efficiently, and thus forms the best general medium for the purpose. The only case where it is at a disadvantage occurs when the burning material is a liquid which is lighter than water and which therefore is able to float on top of the latter and so avoid being smothered, and to a large extent being chilled. Oil is the most important of the liquids which fall within this category, and the paper describes two methods for dealing with it. The first is to cause a heavy incombustible gas to envelop the burning liquid. Very little cooling is brought about in this way but, if conditions are right, smothering is carried out effectually. The heavy gases chiefly used are carbon dioxide and various chlorinated or brominated hydrocarbons, of which carbon tetrachloride and methyl bromide are the best known. To secure effective results, however, the quantity of gas discharged must be adequate, and this for two reasons. In the first place it is necessary for the gas really to fall on the fire, and not be carried away by the fierce rush of ascending products of combustion; and in the second place there must be enough to envelop the fire completely and so shut it off from access to the air. It will be seen that these conditions militate greatly against the use of the heavy-gas method in the open air or in a large building, for the amount of gas needed would render its cost prohibitive. It is certainly the case that small local fires can be extinguished by means of a broad nozzle brought over and in close proximity to the flames, and discharging gas upon them; but this only applies to the ignition of a comparatively thin film of oil of limited area. For all other purposes some kind of enclosure is needed, and this involves the sectionalization of a building into comparatively small compartments, a proceeding which is generally inconvenient or impracticable.

The second method makes use of water, with most of its advantages, but ensures that it does not pass through the burning liquid and so become inactive, by forming it into an emulsion with air, i.e. by converting it into a foam. Two kinds of foam are mentioned in the paper, produced by chemical and mechanical means respectively, the latter consisting of driving a high pressure jet of water, broken into drops by a special nozzle, on to the oil surface. This method is obviously independent of enclosure, is available for any situation, and has provided some of the most effective operations that we have been able to witness in the E.R.A. demonstration.

In the Introduction, the scope of the paper is restricted to fires in transformers and cable ducts, and the tests and demonstrations have been concerned with this type of fire. Speakers at the discussions before other Local Centres have, however, attempted to apply the results that have been obtained to oil circuit-breakers, and in some cases have made drastic statements as to the danger associated with this type of apparatus. Now I hold no brief for the oil circuit-breaker, and am in fact equally interested in the oil-less pattern, but in the interests of accuracy I wish to point out that these conclusions are quite erroneous. In the first place, the disasters that have occurred in power stations have not been due to oil circuit-breakers. The Bradford fire, which has been mentioned, was due, as far as I know, to the ignition of compound emerging from a bushing attached to a metal-clad busbar chamber. The fire at Kingston also had nothing to do with oil circuit-breakers, but began as an open arc which was able to persist until it spread to a transformer. The fire at Nechells about 7–8 years ago originated as a fault inside the bushing of a power transformer. I do not know of a single case where a serious fire has been caused by an oil circuit-breaker.

Further, the conditions under which an oil circuit-breaker works are quite different from those which obtain in the case of a transformer, and which are reproduced in the paper. A typical transformer fire will begin as a short-circuit between the turns of one phase; incidentally, nine-tenths of the faults to which transformers are subject belong to this class. It causes only a small out-of-balance, of say, 10 % to 15 %, and if the protective gear is less sensitive than this, as is unfortunately very often the case, the arc will go on burning under the oil, heating the latter and doing further damage. It may burn its way to earth or between phases before an actual fire has occurred, and then the circuit-breaker is tripped; but it may raise the oil to the flash-point and ignite it before the tripping point is reached. The whole of the oil is then in a more dangerous state than would exist if it were replaced by petrol, and a great deal of cooling and smothering has to be expended upon it before extinction is possible. Whatever happens to an oil circuit-breaker, the oil is always cold, and therefore in a comparatively innocuous condition; it is actually not very easy to ignite cold switch oil. Usually when flame emerges from an oil-switch tank, it is due to the natural evolution of gas as the result of arcing on oil, which, on account of a leaky flange or gasket, or similar defect, is able to reach the atmosphere at a temperature exceeding the ignition temperature of the most easily ignitable constituent, which is probably hydrogen. Since the latter is 590° C., and the temperature at the arcing is of the order of 3 000° C., carelessness in venting the tank may easily produce this phenomenon. It has, however, no bearing upon the rupturing performance of the breaker, and merely consists of a flame lasting 2–3 sec., a very different thing from the ignition of the oil itself. The failure of an oil circuit-breaker, when it does occur, consists of one or the other of the two types described, namely an expulsion of cold oil or short-duration flame; the throwing of burning oil is very rare indeed.

Again, the explosions that are apt to occur in a power station or substation following a short-circuit are popularly supposed to be due to oil circuit-breakers, but this is seldom the case, and even then they are very rarely due to the oil. A short-circuit between busbars, for example, with no oil present at all, produces an explosion that is probably more violent than anything in which an oil circuit-breaker can be concerned; the explosive pressure-rise being due to the instantaneous heating of the air by the arc, augmented by the rapid combustion of copper vapour in air. My own opinion is that the presence of oil will reduce the force of an explosion, by absorbing heat from the arc and preventing the other actions from taking place.

One of the chief lessons that can be drawn from the E.R.A. tests is the vital importance of speed in preventing serious damage. The fierce inflammability of the oil was solely due to its having been preheated for as long as $2\frac{1}{2}$ min., whereby a large volume of flame was produced that was very difficult to extinguish. The radiation from this expanse of flame is able to spread the fire in all directions, by the sheer concentration of heat upon all surrounding objects. In this way all carbonizable material in the immediate vicinity is gasified and at once ignited, and a general conflagration is the result. For this reason, the automatic methods of dealing with a fire are particularly important.

Finally, I think it should be made clear that the " boil-over " which gave such spectacular results in the films is scarcely a practical condition, but was due to an experimental subterfuge, viz. the injection of water below the oil in order to raise the oil-level conveniently.

Mr. J. Woods: It is very rarely that a fire brigade is able to arrive at the scene of a fire, say, 2 min. 50 sec. after the outbreak (not discovery). The film illustrating the E.R.A. experiments showed that in one of the transformer fires a " boil-over " occurred before the water system came into operation. The result was that the surrounding ground immediately became fire-laden, and, while the E.R.A. tests were no doubt carried out under safe conditions, under actual working conditions such safety might not exist. There might be no one present to take additional protective measures, and so far as the fire brigade is concerned an extension of the outbreak, due to " boil-over," might have serious consequences. It seems to me, therefore, that from the point of view of co-operation and the elimination of further damage, the provision of dwarf walls is essential.

As regards the question of determining whether the current has been cut off prior to the bringing into operation of water appliances, there exists in Birmingham a co-operative system whereby the fact that high-voltage electricity is consumed on the premises is indicated by the fitting of a " H.T." plate on the exterior doors, and a fire-brigade officer would not, of course, attempt to bring water appliances into operation to deal with a fire at such premises without first ascertaining that the current had been cut off, either locally or by the high-voltage supply controller.

Mr. J. T. Hole: It is proved conclusively by the E.R.A. film that any type of electrical fire can be put out with water. The fires shown in the film are not true electrical fires, but really material fires; a true electrical fire is one where the power in the circuit must be considered. As far as Birmingham is concerned, the fire brigade usually have to resort to the use of water, which is most abundant.

Dr. C. C. Garrard: The conclusions in the paper as to the best types of fire-extinguishing apparatus to use under different circumstances agree with the experience we have obtained in dealing with oil fires in our high-power testing laboratory. One point, however, which is not mentioned is the relative cost. Carbon dioxide and methyl bromide are expensive, especially the latter. This may be of more importance in a testing station where fires are artificially produced than in power stations and substations where fires are fortunately very rare.

If a fire-extinguishing installation is put in it should be automatic, as electrical fires start very quickly. It seems to me that the best way of tackling the problem is to make the electrical apparatus serve as its own fire-extinguisher. This is at the present moment possible, at any rate as far as switchgear and transformers are concerned.

As regards rotating machinery, we have to consider the fire risk associated with the lubricating oil. As serious fires have been due to ignition of lubricating oil as any that have occurred with insulating oil. In the case of transformers and switchgear, fireproof insulating media are available, but unfortunately not as yet in this country. Media of this sort which have been used here have had to be imported from America, and are extremely costly. One such material I have in mind is chlorinated diphenyl. It can be obtained in various grades, depending on the amount of chlorine it contains. Addition of chlorine increases the fireproofness as well as the viscosity. For transformer cooling where low viscosity is essential, the material is sometimes diluted with trichlor benzene. This class of material, however, cannot be used inside an oil circuit-breaker; but here the oil does not constitute a serious fire hazard, at least in a modern type of construction. The fireproof material can, however, replace the inflammable compound and/or oil generally used in the busbar chambers, etc. Switchgear fires of this sort that have occurred in the past have been mainly due to such compound or oil. A fire having for some reason started, the busbar chambers have fractured and the escaping compound or oil has fed the fire: if this fireproof material had been used, in escaping it would have smothered the fire and saved the situation.

One object I have in mentioning this point is to induce the chemical manufacturers of this country to give attention to the production here of this insulating fireproof oil and compound. If they did, doubtless the price would be reduced and it could be used to a greater extent. Until this is so, oil will no doubt continue to be used. I think that in this connection too much has been made of the alleged fire risk due to the use of oil. I believe such electrical oil fires as have occurred have had serious results not so much because of the use of oil as because of faulty layout. Actually, an oil-filled transformer is intrinsically safer from a fire-risk point of view than an air-cooled one. Fortunately this is now being recognized, and much greater attention is being devoted to sub-division and layout.

It would be a great pity if oil-immersed apparatus, which has rendered such excellent and safe service in the past, were to be condemned out of hand. If we profit by experience such as that detailed in this paper, the fire risk can be to all intents and purposes eliminated.

[The reply of Messrs. J. Hacking and R. A. McMahon to this discussion will be found on page 276.]

NORTH-WESTERN CENTRE, AT MANCHESTER, 2ND APRIL, 1940

Mr. W. Kidd: Fire-extinguishing installations differ in one important respect from plant installations, inasmuch as, though we can and do test the operation of individual parts at regular intervals, we cannot make a thorough and reliable test of the effectiveness of the complete installation.

The supply undertaking in Manchester some years ago engaged a professional fireman, whose duty is to train the works brigades in the various stations and to see that all fire-fighting equipment is tested and kept in good order.

The paper shows that skill in the design of systems and the placing of nozzles, etc., is an extremely important matter. I should therefore like to impress upon supply engineers the necessity for modifying their installations whenever plant and cables are altered.

It is rather disturbing to note how, in some of the tests, fires have persisted. This proves the vital importance of two things; first, that standby equipment of a portable nature should be available; and second that switch-rooms, etc., should have fans or other means of quickly removing smoke and fumes so as to enable men to enter and deal with smouldering matter.

It has been well established that methyl bromide is a quick fire-extinguisher, and only a small quantity is needed. Is it not an argument in favour of CO_2 installations that, since they use larger quantities of gas, small imperfections of the installation and (perhaps) small time-delays are not so important, since they represent a smaller percentage loss of effectiveness?

The paper rather indicates that methyl bromide is quite safe to use, but I have not been able to get a clear-cut statement from the chemists on the question of its toxicity. They seem to hesitate to confirm that it is quite safe.

The tests clearly indicate that if a fire got well under way, inert gas would be unlikely to put it out. A number of installations are non-automatic, although they may be fitted with automatic indicators; I should like to know whether such installations should be ruled out as unsuitable.

I have frequently been informed that a 50 % concentration of CO_2 is quite adequate to deal with any fire, but I calculate that, in the tests described in the paper, concentrations of 75 % to 100 % were used. Is 50 % now regarded as inadequate, and shall we therefore have to increase the capacity of our installations? Our practice has been, as far as possible, to divide the switch-houses and have two banks of CO_2 cylinders, each bank of sufficient capacity to deal with the largest room, with the idea of bringing in the second bank should the first one not prove effective. From the film which has been shown at this meeting, and from what one hears about fires which have occurred elsewhere, it appears that the extreme rapidity with which these fires develop renders that precaution rather useless, and that if a fire has got properly going it can only be successfully attacked by the use of water.

What type of hose nozzle does the E.R.A. consider to be the most suitable for use by semi-skilled firemen when attacking oil fires? I understand that a certain amount of skill is required in using some types of nozzles.

The contractors responsible for installing CO_2 equipment have apparently insisted on the use of screens around transformers intended for outdoor use. I agree with the use of a barrier between two transformers, but there are objections to putting screens close to three sides of a transformer because they adversely affect the heat dissipation under normal working conditions. Further, it seems to me that inert gas is quite unsuitable for outdoor fire risks, and that therefore for such cases one has to rely on the water supply as an extinguisher.

Until quite recently we had been led to believe that a very high pressure of water is essential for fire-fighting, and in cases which I had to investigate we found it impossible to get such a pressure from the town mains. The cost of installing booster pumps, surge tanks, etc., rendered it almost a better proposition to provide a duplicate substation. The result of the tests described in the paper does seem to have been to prove, however, that a low-pressure water installation can successfully deal with a fire.

Mr. D. H. Chisholm: Dealing with the theory of emulsification in relation to fire-fighting, I fail to see how atomized water or water spray can mix with transformer oil burning at 325° F. (the flash-point* of common transformer oils) to form an emulsion. It seems to me that the water must be converted into steam, either during its passage through the flame zone or immediately upon contact with the burning oil, so long as the oil temperature remains above 212° F. In the Birmingham discussion on this paper Mr. Hoyle explained† that the atomized water or water spray is in fact converted into steam until the oil temperature has been reduced below the boiling point of water, after which an oil-and-water emulsion is formed. I agree with Mr. Hoyle that this emulsion, if it occurs, cannot form until the oil temperature is below the boiling point of water; and by that time the fire has, of course, been extinguished, because oil vapour cannot be formed to support combustion below its flash-point of 325° F.

(*Communicated*) The E.R.A. has recommended a minimum running pressure of 50 lb. per sq. in. at the highest nozzle of atomized-water systems when all nozzles are open, and there has been some comment on the fact that it is only with regard to atomized-water installations that the E.R.A. has departed from its stated principle of leaving the actual design of installations to the manufacturers who have submitted equipment for test. No similar recommendations as to operating pressures have been stated with regard to foam, methyl-bromide or CO_2 installations.

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* The temperature at which the vapour driven off from the body of the liquid will support a temporary flame or flash.

† See page 266.

The discharge from an atomized-water system is in the form of divided water drops travelling at sufficient velocity to overcome the effects of rising air currents from the fire and to overcome wind resistance. The second element in the discharge is an aqueous mist which serves to fill the cone of the discharge as much as possible, so as to overcome any tendency to injector action. The extinguishing action of projectors is to be attributed to the three causes mentioned below.

(1) *Circulation of the burning fluid.* Inflammable liquids such as transformer and switchgear oils have a high temperature gradient, and while the liquid is burning the temperature immediately below the upper surface (e.g. at a depth of only $\frac{1}{8}$ in.) may be considerably less than flash-point. The flames are not given off directly from the surface of the burning liquid, but are caused by the combustion of the gaseous vapours which have been driven off from the liquid surface by the raising of the temperature above burning point (the temperature at which the liquid will supply sufficient vapour to support continuous combustion). When projectors are played on the surface of a burning liquid, circulation is set up near the surface, and the lower layers, which are very much cooler by contrast, are brought to the top. The upper layer is then below flash-point, and is in turn cooled by the incidence of further water from the projectors; thus the production of inflammable vapour is completely cut off and combustion ceases.

(2) *The cooling action of the water from the projectors.* Water discharged in the form of drops presents the greatest possible surface to the flames and to the burning liquid in comparison with the volume of water discharged. There is, therefore, the greatest possible heat-transfer between the two liquids; indeed, the hotter the fire the greater is the cooling action by conversion of the water into steam. This cooling action is also of great service in preventing buckling and fracture of the containing structure.

(3) *Excluding oxygen by admitting large quantities of steam.* The aqueous mist which is discharged by the projectors is converted into steam immediately upon contact with the flames. This action is progressive so long as further mist is being supplied, and the steam constitutes a screen or shield through which the drops of water may pass to circulate the surface of the burning fluid, or to cool the structure. In practice large volumes of steam are generated, both from the mist and from the drops, thereby almost completely cutting off the supply of oxygen to the flames. It is well known that the same principle is applied to fire-extinguishing in ships' boiler-rooms, particularly when oil-fired furnaces are used. In this case it is possible almost to exclude air by filling the room with steam and water vapour. Steam is not generally used for fire-fighting other than in such confined spaces, because of the difficulty of directing it from a reasonable distance from the flames. Projectors may in this sense be regarded as a means of directing a steam curtain or barrage, directing the water to the seat of the fire while the fire itself supplies the heat for generation of the steam.

As to the relative importance of the types of action described under (1), (2) and (3), this will depend upon the nature of the risk and, in some degree, upon the cause of the fire. Careful fire tests have been made to prove that conditions cannot arise such as to rule out any one of these types if the nature of the fire and its circumstances demand reliance upon it.

An illustration of this is to be obtained when dealing with fires in partially closed vessels such as would be represented by a transformer which has been split around the top flange by internal pressure. The oil will flow out from the tank to the level of the bottom of the breach and will leave behind a space inside the tank in which combustion will continue, assuming the breach to be large enough to admit sufficient air. It is not feasible to assume that projectors can be located so as to play directly into this opening, because this condition might not occur in practice. Such a fire, then, must be extinguished without employing (1) and (2), which means that full reliance must be placed on (3), i.e. on the presence of steam. This calls for accurate spacing of the projectors in relation to the tank, with careful direction of their discharge. Such fires are in fact readily detected and extinguished by means of atomized-water systems, the action being almost instantaneous.

It is at times necessary to provide protection to spaces which cannot be reached with overhead projectors, such as the under-side of large transformers and oil storage tanks. For this purpose another type of projector is used, the discharge from which is in the form of a very flat hollow cone, having a wide range of action.

When these principles were applied at the Barking tests, shorter extinguishing times and smaller quantities of water were recorded than in any of the other experiments recorded in the paper. The fire in the case of Test 44 was the most severe and occurred under the most difficult wind conditions of the series (speed 19–24 m.p.h., with occasional gusts at 30 m.p.h.); it was extinguished in 27 sec. with a water consumption of only 145 gallons. The atomized-water installation used in this test had a running pressure of 16 lb. per sq. in. at the topmost projector. The E.R.A. has stipulated a minimum of 50 lb. per sq. in. without putting forward practical reasons for this choice. This pressure does, however, represent a very large reduction from the 105 lb. per sq. in. employed on the installations designed upon the theory of emulsification. It has been suggested that a higher pressure than 16 lb. per sq. in. is warranted in order to avoid boil-over; but as boil-over occurred with the high-pressure system at 105 lb. per sq. in. this cannot be the case.

Mr. S. R. Mellonie: Most of the information given in the paper was known in a general way at least 10 years ago, and certain installations of the automatic CO_2, foam, and methyl-bromide types which date from that period would require very little alteration to bring them into line with the present recommendations. The paper makes no distinction between chemical-foam and mechanical-foam extinguishers; I should like to know which proves the more effective.

We have made considerable progress in regard to ease of testing of fire-fighting apparatus. For example, we have devised a simple means whereby automatic CO_2 installations can be tested right back to the dropping of the weight. Further, we have made arrangements for testing electrically-operated methyl-bromide installations by merely pressing a button. In this case the whole operating gear is tested, with the exception of the discharge of the methyl bromide.

It is desirable to avoid having exposed mechanical controls, as where these are fitted it is only a matter of time before an energetic workman with a ladder causes an accidental discharge.

Some 8–10 years ago we decided that water was an extremely undesirable agent to use on switchgear, because of the damage which it causes.

Mr. F. P. Spicer: It is stated on page 723 that " Inert gases such as methyl bromide and carbon dioxide cause extinction by exclusion of oxygen, the cooling effect being practically negligible. Water, on the contrary, causes extinction by cooling. Foam causes extinction mostly by its smothering effect, thus excluding the supply of oxygen, and to a relatively small extent by its cooling action." There is something tentative about this statement regarding foam, and I feel sure that if the real extent of cooling by foam were thoroughly investigated some surprising values would be revealed. There are three distinct methods of producing foam. The first consists of mixing two chemical compounds in certain proportions, when chemical action produces foam as required. The second consists of mixing certain dry chemicals in powder form and applying water to these in a suitable container when foam is required. Both of these produce what I will call " chemical foam." In the third method, which gives " mechanical foam," water mixed with approximately 2 % to 2½ % of special liquid is passed at certain pressures through specially designed branch pipes, either fixed or portable, which draw in air and produce a continuous stream of strong foam.

It is well known that where ordinary water streams are used only a small percentage of the water (possibly 1 % to 1½ %) is able to function as a cooling agent, because on account of its mass and momentum no substantial surface area of the water can be exposed to the fire. On the other hand, mechanical foam has a water content of only 10 % to 12 %, but this water is split up into very thin layers represented by the foam bubble wall, thus exposing an enormous cooling area. The proportion of this water content which is useful for cooling is probably 50 %, but the figure will vary according to the degree of foam formation and the fluidity of the foam at the moment of application to the fire. A foam of medium fluidity spreading quickly over an oil surface cools the surface layer, retarding the evolution of inflammable gases, and therefore extinguishing the fire.

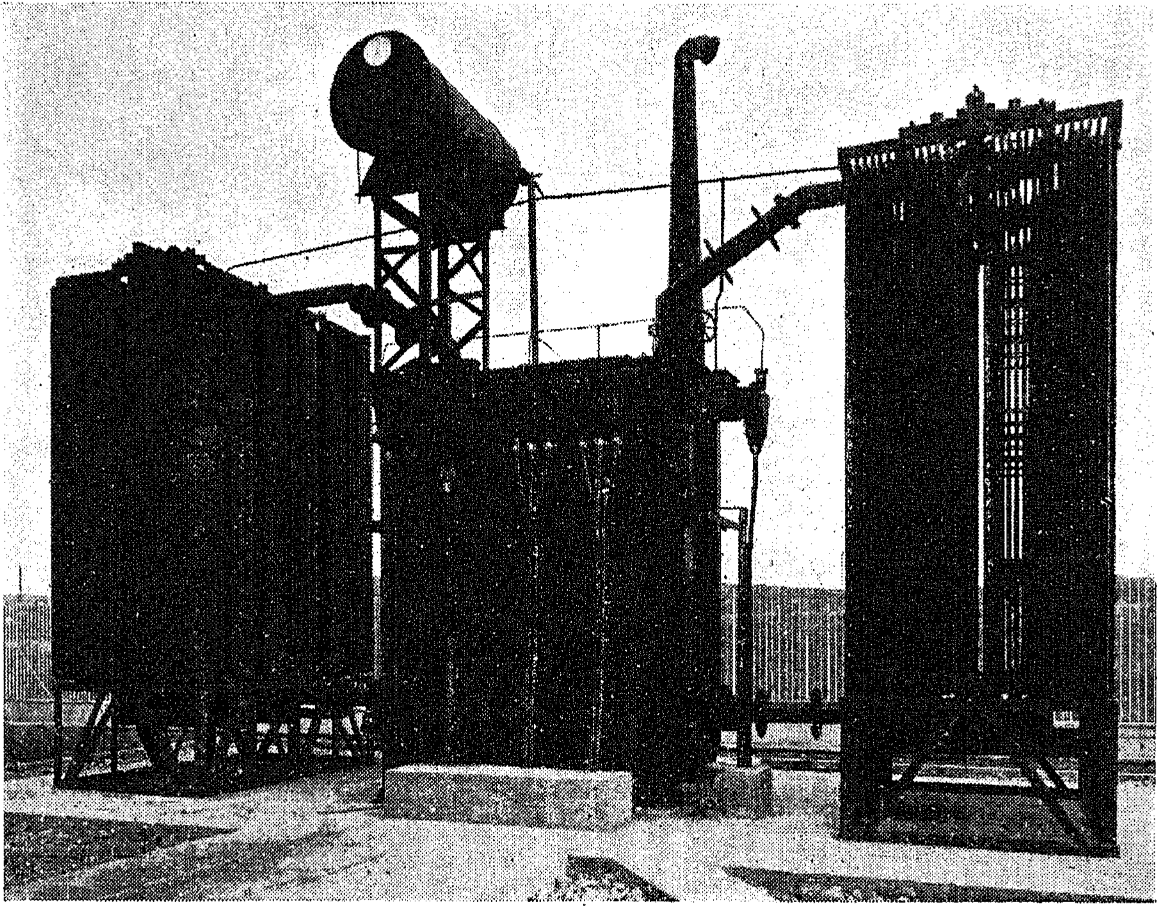
Fig. A

Turning now to a consideration of the water required for foam installations, the paper shows that on the 8 outdoor oil fires with fixed nozzles the amount of water used varied between 145 and 900 gallons, or an average of 480 gallons per test. Taking an average figure for the ratio of foam expansion to water used, as 8 times, the water used on the foam tests for the same outdoor tests (with fixed nozzles) varied between 112 and 470 gallons, or an average for the 2 tests of 290 gallons, i.e. only 60 % of the consumption when water alone was used. Further, on the outdoor tests with portable nozzles the water used amounted to 1 150–2 330 gallons, or an average of 1 740 gallons; whilst the water content of the foam used was

133 to 270 gallons, or an average of 200 gallons, i.e. only 12 % of that required when water alone was used. Similarly water rates in gallons per minute show important differences as between the two methods. In the foam tests the average figure was 100 gallons per minute, whilst in the water tests it was between 300 and 400 gallons per minute. Many town water mains capable of supplying 100 gallons per minute at a reasonable pressure would fail if called upon to deliver 300 to 400 gallons per minute.

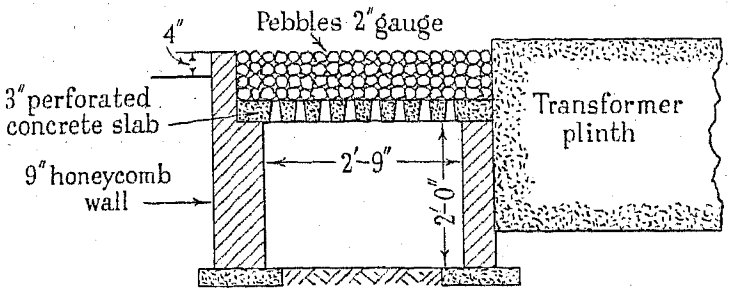

Fig. B

Mr. F. Favell: Figs. A, B and C illustrate work which has been completed and complies with the various recommendations made appertaining to the subject matter of the paper. They show parts of a 33-kV substation containing 750-MVA metalclad switchgear controlling incoming C.E.B. supplies, outgoing circuits and 15 000-kVA interconnecting transformers.

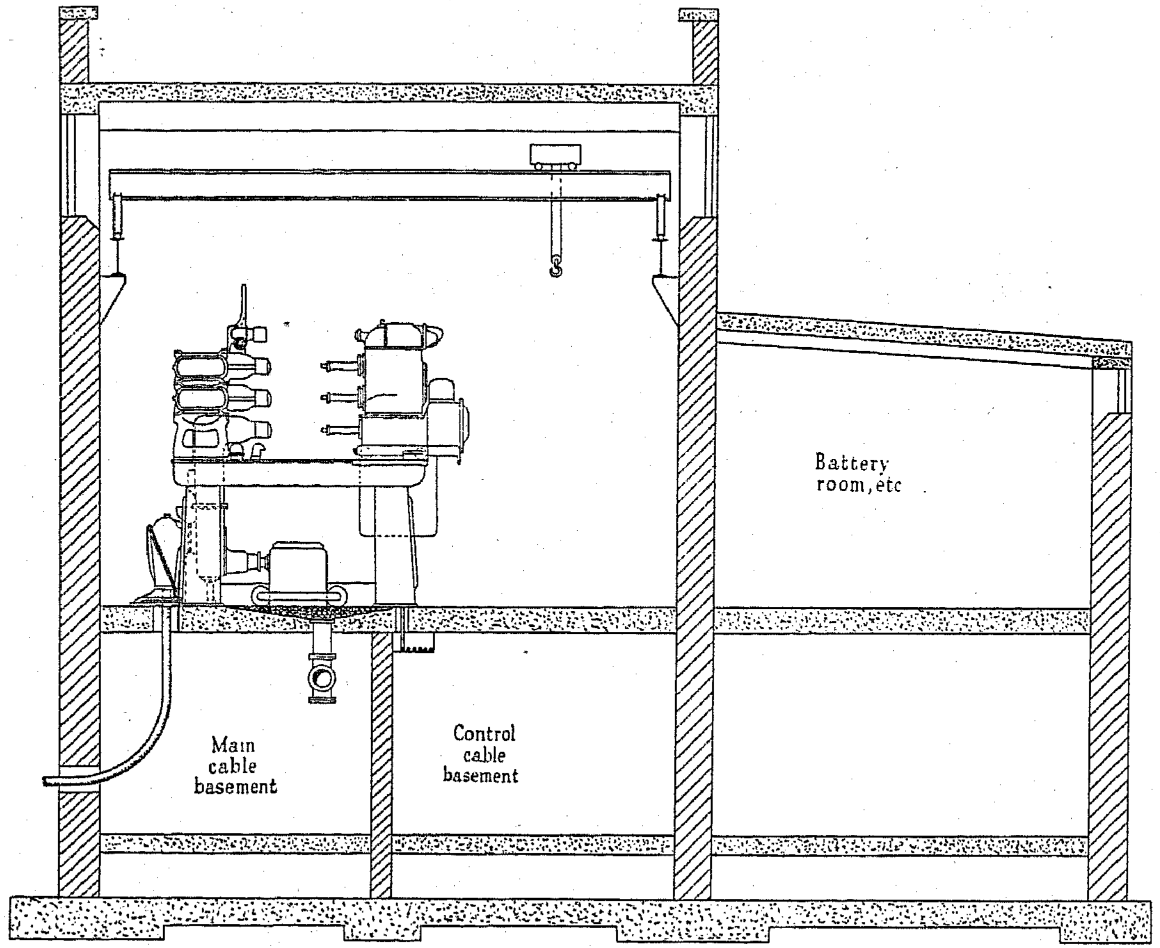

Fig. C

Fig. A shows the arrangement of the 15 000-kVA 33/6·6-kV step-down transformer. This particular transformer had been on fire following trouble on a neutral connection cable box. The fire was extinguished before much damage had been done. The specially constructed cable trenches were largely responsible for the efficiency of the fire-fighting work. The trenches appear to be full of large pebbles.

Fig. B shows a cross-section of the trench, which consists of an upper and a lower chamber divided by a perforated concrete slab. The volume of the empty space under the slab is just larger than the total volume of the oil in circuit. The pebbles cool the oil, which is allowed to soak away or be drained off through the open joints in the brickwork.

Fig. C shows a cross-section of the 33-kV substation, indicating the construction and arrangement. The chief features are the roomy divided basement separating the main and multi-core cables, the splinter-proof walls and the method of dealing with oil, which would be carried away through the pebble-filled recesses in the floor.

Mr. A. G. Ellis: It is concluded in the paper, I think rightly, that atomized-water extinguishing is the most suitable for outdoor work. If inert gas is used, screens are needed, and, as the E.R.A. films indicated, screens are not particularly efficacious, especially if there is a wind. To provide adequate screens is costly, but one circumstance has arisen lately which rather offsets the cost, namely the recommendation that, for the air raid protection of large outdoor transformers, screens should be built around them. The screens will serve a double purpose—in fact, in some cases, a treble purpose—as they act also as noise-limiting shields. Where party walls between large transformers are built for the purpose of preventing the fire from spreading from a transformer to its neighbour, they can be utilized as part of the screening.

Regarding the question of possible damage to electrical plant by fire-fighting media, as I had some misgivings as to whether atomized water would leave any deleterious effects behind it I had some tests made at the works of one of the suppliers of atomized-water fire-fighting equipments. The tests were made on an oil-immersed transformer in which the oil was ignited at the top surface and the fire extinguished by atomized water from above. The only damage caused by the fire to the transformer was the charring of terminal leads and of the bakelite-tube driving spindle for the tap switch, where they projected above the surface of the oil. The windings and insulation were not damaged, and drying presented no difficulty.

Dealing with the subject of dwarf walls for preventing burning oil from spreading, such a wall should be sufficiently high to prevent the oil from flooding over the top in the event of a bad tank burst. It is preferable to drain the oil away, although it has been found that oil burning for some time around a transformer, outside the tank, has not damaged the transformer itself.

Where oil is drained into a tank or sump through pebbles or stone chippings, in order to effect quick extinction the arrangement should be such that the oil passes completely through the stones and does not remain flooded above the surface; in the latter case it would continue to burn until the surface was reached.

The cubical content in the interstitial spaces should be sufficient to allow for the oil level to be several inches below the surface level, and the top layer should be of small stones or chippings. Where the arrangements are such that the oil drains away, large pebbles can be used.

Mr. H. G. Bell: By installing suitable fire-fighting equipment it is possible to reduce very materially the risk of a prolonged interruption of supply, but since it is not possible to guarantee complete extinction in every case a certain risk remains.

The only way of making quite certain that fire cannot cause serious disturbance is to segregate effectually the switchgear, so that a fire in one section cannot affect the remaining sections. To install fire-fighting equipment is a most important safeguard, but it cannot obviate the necessity for complete and satisfactory segregation.

Whatever type of fire-fighting equipment is provided, consideration should be given to the possible effect of an accidental discharge of the fire-fighting medium both on the gear and on men who may be working in the vicinity.

Mr. J. Kennedy: In the Barking tests methyl bromide proved to be exceedingly effective, and the fact that a small quantity was used does not militate against its efficiency when compared with that of CO_2. I do not agree with Mr. Kidd's suggestion that a small loss of CO_2 would not matter, whereas the equivalent loss of methyl bromide might. The manufacturers of CO_2 apparatus do not suggest a 50 % concentration because they want to, but because they wish to give an adequate measure of safety. I think that in practice the losses are proportional, although methyl bromide is exceedingly heavy and is not dissipated very readily, as the E.R.A. film shows.

Regarding the delayed-action tests, one point worth bearing in mind is that, if gear has been burning $2\frac{1}{2}$ to 3 min., irrespective of whether the fire goes out the gear will have been effectively shut down. I am not endeavouring to detract from the efforts of those manufacturers who were successful in the delayed-action tests, but only to emphasize the necessity for automatic operation.

A water fire-fighting system is probably the best for outdoor installations, but with a small electrical installation the cost of equipment for extinguishing by water might be prohibitive, and in that case a gas type of extinguisher would have to be used. For A.R.P. reasons it is necessary in a great many cases to put in screens, and therefore their cost is not necessarily a charge on the fire-fighting gear.

Mr. W. A. Crocker: One aspect of the subject which has not been stressed is the possibility of fire arising out of an explosion within a transformer or switch, the oil being thrown about. The authors recommend that dwarf walls should be far enough distant to catch burning oil, yet in an example shown on the screen by a previous speaker the dwarf walls appear to be only about 2 ft. from the transformer. I would ask whether the E.R.A. would consider it safe to erect the water supply pipes on divisional walls, as an explosion might disturb the installation and possibly cause a solid jet of water to be thrown on to the fire, instead of spray. I think due allowance should be made for the possibility of removal of screen walls, roofs or windows by explosion when providing for the necessary concentration of gas.

As regards the possibility of disturbance to the operating wires of an installation by accident, it appears to me that electrical detection has advantages in that the wiring, in conduit, can be placed in safe positions.

The small swabs used for firing in the tests were apparently difficult to extinguish; I have seen cases where for the sake of tidiness sawdust has been spread beneath a transformer, and I am wondering whether the authors would consider this a dangerous practice.

Mr. H. C. Leech: I should like to know on which tests mechanical foam was used and on which tests chemical foam was used. Secondly, I should like to know how the cables in the cable trenches were ignited. If they were ignited from the outside the temperature would surely not be so high as if they were ignited by some electrical fault from the inside. The fire would not have been extinguished so quickly with foam had the trouble begun from the inside. What type of chemical carrier was used for propelling the methyl bromide? These propellants can vary tremendously, and also affect the extinguishing qualities of the methyl bromide.

I should like to know why chemically pure carbon tetrachloride propelled by dry CO_2 was not used. If it had been, there would not have been the same necessity for screens.

Mr. E. Mead: With the horizontal draw-out type of metalclad switchgear supplied until quite recently, the open-type side frame was usually used, so that should damage occur to one oil circuit-breaker unit and the oil escape from the tank and become ignited, the burning oil could spread through the side frames to adjacent units, and so affect, possibly, the whole switchboard. In most cases it is possible, even with old-type apparatus, to fill in the side frames, so that each circuit-breaker is virtually in its own compartment. In this way the possibility of trouble on one circuit-breaker spreading to the adjacent units can be minimized.

Another point which should be watched is in connection with the rails on which the voltage transformer runs. It is usually found to be convenient to form an oil sump between these rails to drain away any oil which may escape from the oil circuit-breaker tank, but if the rail projects above the level of the floor a well is formed between the outer edge of the rail and the side frame. Oil can be trapped in this well and, if ignited, may burn for a considerable time. It is suggested that on existing installations this well should be filled up with cement, and that on new installations the level of the floor should be brought up to the top of the voltage-transformer rails. With this arrangement any free oil on the substation floor automatically drains away into the oil sump between the voltage-transformer rails.

Mr. D. R. Davies: The value of the paper would have been increased by the inclusion of information to guide the buyer in preparing a specification for the CO_2 installation. I have found the various manufacturers of fire-fighting equipment very helpful when considering schemes for use with switchgear, but unfortunately there is a marked lack of unanimity in the recommendations made by individual firms.

Those interested in this subject will find some useful information in a booklet published by the National Board of Fire Underwriters (U.S.A.). Unfortunately, there is no equivalent British booklet, and there appears to be ample justification for a British Standard covering the application of CO_2 equipment to buildings containing electrical apparatus. I suggest that this could, with advantage, cover recommended concentration of gas in relation to building volume; size of cylinders; size of pipes; spacing of nozzles; operating limits of release coils, etc.

Mr. W. N. Royley: I regret the omission of the subjects "Personnel" and "Training" from this paper. Besides the right sort of apparatus one needs a correctly trained personnel to obtain maximum efficiency for maintenance and use. I have made it my business to take up training, to visit brigades, A.F.S. units, works units and manufacturers' demonstrations, and as a result I am fully convinced of the great necessity for a revised standard training. The electrical industry ought to develop a new basis of strength of personnel, a new basis of well-ordered training and, if necessary, a short-time course of instruction for instructors and leaders.

A fire-fighting works unit should also carry some authority to enable them to put into effect training, recommendations, precautions, inspection of buildings and equipments, etc., and, whenever the emergency arises, to enable them to go about their duties without untrained and unnecessary interference.

A basis for assessing personnel, equipment, etc., might be (1) floor area and valuation, (2) degree of national importance, (3) vulnerability.

With regard to defensive walls, consideration has apparently been given to questions of sabotage and A.R.P. rather than fire-fighting, but I should like to suggest that where surrounding walls are built they should have apertures or loopholes in them, to give a degree of protection to the fire-fighters and allow for the use of branch nozzles, etc. The oil-overflow drainage should receive greater consideration than has been given in some cases.

Mr. T. C. Christianson: I should welcome some information as to the methods to be adopted for controlling incendiary bombs.

I am not aware of what sort of provision it is usual to make in generating stations and important substations in the way of providing the fire-fighting personnel with breathing apparatus as distinct from war-gas respirators. Some fires are accompanied by enormous smoke concentrations which make it difficult for the fighters to get to the distance at which heat becomes the limiting feature.

In the early days of the grid, experiments were carried out with jets of water applied to 132-kV live lines. It would be interesting to know the minimum approach distances considered safe for apparatus which is alive at the usual service voltages, and also whether there is any appreciable difference for jet and spray discharges of water from a metal nozzle held in the fire-fighters' hands.

Mr. J. Atack: Have the authors tested, or do they know anything about, a chemical which it is claimed can be put in certain extinguishers for extinguishing, as distinct from controlling or intensifying the burning-out of, an incendiary bomb?

Mr. G. Barnard: It has been my misfortune to investigate numerous breakdowns of electrical plant, and during the last few months I have had a veritable spate of turbo-alternator failures. When a breakdown occurs, the period of short-circuit or earth fault is often sufficiently long to establish a fire of the adjacent insulation. The fire is prolonged after the unit has been isolated, and the damage is often very extensive. Now it occurs to me that a modern smoke-detector, suitably placed, will serve the double purpose of limiting fires and augmenting the electrical protection of valuable machines. I am not aware, however, of any case where a smoke detector has been fitted in the closed air cooling system of an alternator or large motor.

I am still busy investigating an alarming accident which took place some weeks ago in a power station. A fire broke out in the h.v. switch-room, which contained a 20-kV switchboard comprising about a dozen ironclad oil-immersed draw-out type 500-MVA circuit-breakers. Surges of high magnitude were felt on the system, and simultaneously one of the circuit-breakers gave trouble. This breaker was in the racked-in position, but the switch was not closed. Examination of the switch later in the maker's works revealed that arcing had occurred across the stem insulators from the live side to the load side of one phase and to earth, and a hole about 2 in. diameter had been burnt in the tank. Inspection on site led me to believe that the burning oil had been ejected through this hole, as the walls of the switch-room were scorched right up to the roof. The wood handles of tools on the walls were burnt, the labels were burnt off most of the panels, and a pair of rope blocks in the roof were found smouldering.

There was a set of fixed CO_2 nozzles above the switchboard at the front, and a similar set at the back of the board. The fusible links in the automatic fire-fighting equipment ruptured smartly, and the CO_2 promptly extinguished the fire. At the same time, however, all the glass was blown out of the roof (about 20–30 ft. above the top of the board), and the air blast apparently passed over the back switch-room wall where there is a large gap, say 15 ft., between the top of the wall and the roof, and down into the transformer cubicles on the ground floor—the 20-kV board is on the first floor next to the turbine room. Some of the large steel roller shutter doors were "bellied" outwards and badly distorted. A door at one side of the station on the ground floor, about 25 ft. below the switch-room, was blown off its hinges and hurled outwards across the yard. Fortunately the attendants were at the other end of the station at the time.

Now we are faced with three theories: (1) There was a coal-dust explosion immediately after the switch fired. (2) An explosion of oil vapour occurred which caused an air pressure wave. (3) The CO_2 was discharged at such a high rate that, despite the very spacious nature of the rooms, a pressure-rise was set up sufficient to damage the building.

Regarding theory (1), there is a fuel-pulverizing plant nearby, but careful inspection satisfied me that the switch-room was spotlessly clean and that, as there was no deposit on any of the surfaces, we could rule out a coal-dust explosion. Theory (2) is still popular with some of the persons concerned. It must be remembered, however, that none of the switchgear was wrecked; indeed, the damage to the switch was relatively slight. There were no flying fragments and the damage to the switch appeared to have been caused by burning, not fracture. Theory (3) makes one look further into the automatic fire-fighting equipment.

I have described this accident at some length in order to illustrate the necessity for adequate vents in switch-rooms, substations, etc. There were no vents in the roof here, but some of the transformer cubicle doors had louvres at the bottom, and it is very significant that these doors were not damaged.

(*Communicated*) We must not lose sight of the fact that fires associated with electrical plant usually start by some failure which has developed within the apparatus, and if we can augment the electrical protective devices in such a way as to render them more sensitive, we are tackling the problem at the right end. I have seen large transformers badly damaged which might have been saved if they had been provided with some form of sensitive fault-detector such as the Buchholz relay. I am not belittling automatic fire-fighting equipments; indeed, I think they should be installed wherever they are applicable. The real point I wish to make is that it is more important to adopt measures to limit the possibility of fires starting within electrical apparatus.

With the same object in view I suggest that when laying down electrical plant and switchgear it should be borne in mind that oil is very inflammable and therefore the practicability of dispensing with oil-immersed gear as the circumstances permit should be fully explored. Ionization and condensation in high-voltage transformers, of course, are difficulties which at the moment appear to be capable of being solved only by complete filling with oil, but I believe non-inflammable oils can be used. There appears to be room for further research in this direction.

Mr. J. R. Richardson: Regarding Mr. Mellonie's remark about the possibility that a workman with a ladder may cause an accidental discharge of fire-fighting apparatus, this could not happen to well-designed and well-erected CO_2 apparatus because the actuating gear is in conduit and the only exposed part is over the switch, where no man would go with a ladder.

To get effective mechanical foam it is necessary to have 90 % air, 8 % water and 2 % Saponin. Such a mixture is not obtained with the usual portable apparatus, without a special pump. Chemical foam contains CO_2, which has a cooling effect on any surface upon which it impinges. Whereas the water system is only effective at those points where the nozzles are placed, with the CO_2 system the gas rises all round the whole of the switchgear and helps to extinguish the fire.

I should like to give some particulars regarding spray nozzles. One type of nozzle I have in mind, when directing water on to 32 000-volt switchgear at 6 ft. distance, gives a current of only 1·2 mA. Thus a spray nozzle is very effectual in cases where the fire-fighters can get into the switch-room. But some of the older switch-rooms are very long, and I defy any man to enter one with a hose or other hand-operated apparatus, to extinguish a fire. I suggest that the segregation of switchgear is the best means of tackling this question. Each switch-room should be fitted with automatic CO_2 gear.

Mr. A. R. Milne (*communicated*): I am particularly interested in the references in the paper to automatic and non-automatic operation of the fire-fighting equipment, and it seems to me that the relative effect on the safety of personnel is not sufficiently emphasized. I suggest that perhaps a deciding factor in the case is the degree of probability of a man's being overcome by the extinguishing medium should he be in the room at the moment of release.

Take, for instance, a CO_2 installation in a power station with large main switchgear grouped in separate rooms which by their nature do not permit of rapid exit. One can quite imagine an accident involving the rapid emission of heat which would energize the thermostats and, in the case of automatic gear, release the CO_2 before a man who happened to be in the room would have time to escape. Where the installation is of the remote-controlled, but non-automatic, type the energizing of the thermostat merely gives the alarm in the control room, and if the indicating lamp is mounted directly above the corresponding control switch the danger of releasing the gas in the wrong place would seem remote. Moreover, the presence of a man in the switch-room would be indicated by means of a card hung on the CO_2 control panel, thus ensuring delay in the operation of the release valves until the control room was satisfied that nobody would be endangered by the release of the gas.

Another related point is the provision of dwarf walls in rooms not originally designed for them. A case is known of a switch failure involving the release of burning oil in a room where a dwarf wall had been built across the floor to localize oil flow. In the natural excitement of the moment a man rushing across the room overlooked the wall, fell headlong over it and was injured both by this accident and by the burning oil. He would then undoubtedly have been killed had the CO_2 been automatically released, but as the accident had been observed it was possible to remove him before the valves were opened.

[**Mr. H. Hoyle** also took part in the discussion. The substance of his remarks will be found in the report of the Birmingham discussion (see page 266).]

THE REPLY OF MESSRS. J. HACKING AND R. A. McMAHON TO THE ABOVE DISCUSSION

Messrs. J. Hacking and **R. A. McMahon** (*in reply*): During the course of the discussion both at London and at the various Centres, many speakers raised a number of interesting points which, although quite relevant to the general problem of fire protection and fire fighting, did not come within the scope of the investigation upon which the paper and the film were based. This investigation was to study the limitations and fields of application of the various media available at the time the tests were carried out.

Messrs. Bellerby, Leyburn and Royley, for instance, contend that the questions of personnel, training and drill are of the greatest importance. We thoroughly agree with this view.

The same remark applies to Mr. Lambert's suggestion that the location of the thermostats is worthy of close consideration. Again, Mr. Christianson and others deal with the problem of the application of water to live gear by means of hand-operated branch pipes. This question is already engaging the attention of the E.R.A., and a report will be issued in due course.

Mr. Bright mentions that the paper seems to deal more with the problem of power stations and substations. This is so, but it is evident that the data derived from these tests can be applied to indoor installations of this type. One particular aspect of this question is engaging the consideration of the Committee.

Whilst we agree with Mr. Leyburn's views on the importance of electrical protective gear, this aspect of the problem was not part of the investigation. Nevertheless, even if every circuit were protected by fast-moving electrical protective systems, it would not be safe entirely to eliminate fire protection from major installations. In spite of the very high degree of perfection to which many of these relay systems have been brought, the possibility of a failure remains, and even should the electrical protection function properly there is always the possibility of a fire being started. Whilst it is true that the fire protective system may be damaged by explosion from electrical or other causes, this also applies to electrical protective gear.

Mr. Coates suggests that the Electrical Research Association could usefully devote some time to the investigation of non-inflammable liquid dielectrics. This problem is receiving attention.

Mr. Bellerby's contribution to the Newcastle discussion constitutes a masterly summing up of all the evidence produced in the paper and of that obtained by his own company. It deals with many points raised by other speakers, not only at Newcastle but at other Centres. His remarks will repay any time and trouble taken in considering them with care.

Test Fires

Dr. Barclay remarks that although the film gave the impression that some of these fires were very intense, they were not actually so in practice. The engineers representing the firms who took part in these tests were unanimously of the opinion that the fires were very severe. The opinion of experienced officers of the fire brigades who were present was that the fires produced on test were as severe as any they had met in practice.

Dr. Barclay remarks that fires in the open with the wind blowing the flames off the oil cannot be intense, but in a later statement he says that " The oil vapours arising from burning oil have a narrow range of inflammability so that until they have been diluted by air they tend to suffocate themselves." Now we cannot have it both ways—either you have a fire in a confined space where radiation back to the fire may be of a high order, but in this case, as Dr. Barclay says, the heavy oil clouds partially asphyxiate the fire, or you have a fire with sufficient supply of air to produce the maximum rate of combustion. In the tests carried out at Barking on the outdoor installation the framework became red hot on several occasions, and in a number of tests was hot enough to burn through the thermocouple wires.

In his communicated remarks Dr. Barclay refers to the phenomenon of frothing of oil under certain conditions, and his remarks tend to throw some doubt on the validity of the results obtained. He suggests that frothing might take place as a result of the admission of water under the oil or as a result of applying water to the surface of the oil, and that where it did take place the fire would be self-extinguished. On the majority of the tests water was not applied to the surface of the oil and an examination of the film will show that there was certainly no self-extinguishing action since the fires proceeded sometimes for prolonged periods. We are therefore satisfied that no frothing affecting the test results did in fact take place owing to the admission of water under the oil.

As regards frothing due to the admission of water on the surface, we understand that Dr. Barclay's main point is that the application of water under low pressure may cause frothing under certain conditions and immediate self-extinguishment of the fire, but that under other conditions this action would not take place and the application of the water would be ineffective. This view is interesting but it was not before the Committee when they decided to recommend a minimum pressure of 50 lb./sq. in. This recommendation was made having in mind the obvious risks of steam generation under the oil and consequent boiling over, which they felt could best be guarded against by the use of a reasonably high pressure, which on general considerations they put at a minimum of 50 lb./sq. in.

It must be emphasized that E.R.A. Report Ref. V/T7 gives a detailed account of the tests, the conditions obtaining during each test and a detailed description of the installations used. It does not purport to contain any conclusions or recommendations, but these are contained in the present paper (also published as E.R.A. Ref. V/T8). Obviously nobody should take action based on a purely descriptive document without consulting the conclusions drawn and the recommendations made by the Committee which conducted the investigation and had therefore all the facts in its possession. If this is borne in mind the apparent discrepancy to which Dr. Barclay refers entirely disappears.

Several other speakers have criticized the test fires from different angles. It is obvious that in one installation it is impossible to incorporate all the possible complications and combinations which may occur in practice.

It can be said that the actual fires in this installation were very representative of what can be expected should a fire start in a transformer or switch installation. Mr. Chisholm remarks that under electrical conditions an arc under oil gives off approximately 80 % hydrogen, and infers that because hydrogen decomposed from oil was not present in these tests, the results obtained with inert gases were not representative. In any fire in electrical apparatus the amount of oil decomposed into hydrogen, acetylene, etc., is very small compared with the bulk of oil in the installation, and unless the arc is allowed to persist for considerable periods the amounts of gases formed will be small.

Mr. Leach asks what method was used to ignite the cables. The method is explained on page 722, where it is stated that the cables were ignited from the outside. Had ignition taken place from the inside, it is agreed that the temperature at the actual point of the fault would have been very much more intense, but it would have been strictly localized. In the tests carried out, the lead covering of the cables was melted and had run almost along the entire length in every test, bearing proof of the severity of test conditions which, in our opinion, were as difficult as if the fire had started from within. The conditions referred to by Mr. Leach can only be more severe than this as long as any arcing persists. Arcing should be taken care of by the electrical protective system and not be left to fire protection to cope with. Fire protective systems are designed to cope with the after-effects of arcs and not with arcs themselves.

Mr. Coates does not think that 2½ minutes was long enough to allow before attacking the fire. It must not be forgotten that in these tests the oil was preheated before the fires started, and test experience showed that under the conditions of our own testing plant, maximum rate of combustion usually occurred between 1½ and 2½ minutes, after which the fire did not appear to increase in violence as a function of time. This was not so in a few cases, therefore longer time-delays were allowed.

Questions Arising out of the Use of Inert Gases

Loss of gas.

One or two speakers appear to think that because the volumes of CO_2 installed were larger than those of methyl bromide for a similar risk, the latter would be at a disadvantage in case of leakage or by other loss of gas. In this connection the phenomena of fire extinction by inert gas must be well understood. Extinction depends not upon the exclusion of oxygen, but upon its dilution to a degree at which it will no longer support combustion. Mixtures of oxygen and certain other gases have an inflammability range in the same way as an explosive range. Certain gases, such as methyl bromide, carbon tetrachloride vapour and CO_2, when mixed with oxygen in certain quantities depress the combustion point, and each at a definite percentage inhibits combustion. It is not the absolute quantity which is of importance, but the percentage concentration. We therefore agree with Mr. Kennedy when he says that losses of methyl bromide and CO_2 are proportional and that, provided the same margin of safety has been left in an installation of each type, methyl bromide does not suffer any disadvantage on account of the smaller quantities used. At the same time it must not be forgotten that the storage pressure of methyl bromide is only a fraction of that necessary for CO_2 storage, unless, of course, the low-pressure system is used.

The Cooling Effect of CO_2.

Although CO_2, being at a very low temperature, must necessarily have some cooling action, this is small and limited in scope. It is true, as Mr. Lambert points out, that in five CO_2 tests the average drop in temperature was 30 deg. F., but in one case there was an actual increase in the temperature after the conclusion of the test.

Injection of Gas.

Mr. King asks whether the introduction of inert gas into the transformer has been considered. Experiments have been carried out by bubbling CO_2 up through the oil, and this method has also been used in the protection of dip tanks. The experiments on transformers were not successful, and we believe that this method of introducing inert gas into dip tanks has been discontinued, as it did not give satisfactory results. The chief difficulty is to avoid violent ejection of the burning liquid by the inrush of CO_2.

Standards

Mr. Davies refers to the booklet published by the National Board of Fire Underwriters (U.S.A.) which deals with the requirements laid down for CO_2 installations. We agree that these booklets serve a very useful purpose and could be extended to all types of media. It must be realized, however, that the N.B.F.U. specification does not constitute an American standard and it is doubtful whether the compiling of a British standard as usually understood would serve the purpose. We do sympathize with Mr. Davies's views, but we suggest that a complete specification sponsored by the insurance companies should be made available. We hope that the paper may be of some use as a stepping stone in this direction, at least so far as electrical installations are concerned.

Times of Extinction

We do not agree that one is led to believe that the fire only flickered out at the end of the discharge. Mr. Lambert contends that extinguishment occurs when there is a characteristic dense cloud of CO_2 completely overwhelming and filling the space. It is precisely this dense cloud which causes difficulty in observation, and as in these circumstances it is impossible to give a precise figure as to the instant of extinction it was deemed better for the purposes of these tests to leave it alone.

Effects of Explosion

Mr. Barnard describes an incident in which damage was done to a building where the installation was protected by CO_2. He leaves us to draw the inference that the damage was caused by a pressure-rise due to the CO_2 discharge. From the extent of the damage sustained, it does not seem possible to us that the CO_2 installation can be blamed. The discharge of CO_2 may have caused a certain rise of pressure, but this rise could not have taken the form of a pressure wave of sufficient amplitude or duration to cause the damage described.

In our opinion the damage could only have been caused by an explosion of products set free by arcing under oil. Mr. Barnard states that the damage to the switch was caused by burning, not fracture, but the burning must have been the result of arcing. If this arcing occurred within the switch and under the oil, it is very likely that hydrogen and acetylene were formed under pressure. At this point several things may have happened. For instance, the tank bolts, especially if of the long type, may have extended under the stresses produced, opening a gap between the cover and the tank itself and allowing the gases to escape. The tank may have bulged or the tank cover may have sprung. Should any of these things have happened without exceeding the elastic limit of the materials concerned, they would return to their normal state after the release of the pressure without leaving any visual evidence of what had occurred. Engineers with switch-test experience will confirm that, on heavy tests above the normal capacity, oil is sometimes projected from switches without causing any apparent damage.

Mr. Leach also suggests tests with explosions to rip open the tank. This point had received careful consideration, but was found to be impracticable and would have increased the cost out of all proportion. In fact, it would have meant a new installation for each test.

We are inclined to agree with Mr. Gilbert that foam would check a fire, even if the installation were partially destroyed, but as no tests were done this is only an expression of opinion. In regard to gas, the effect of damage to the installation is more difficult to forecast. It might give rise to the condition mentioned by Col. Lyon in connection with the Detroit Fire School. In that case no shrouds were fitted to the nozzles, which pointed downwards towards the tray. The jets of CO_2, blowing on the surface of the petrol, churned it up, causing vapour to rise to the ceiling and explode before the CO_2 could get there. Proper design of the installation would have prevented this, as was subsequently shown by a series of tests in the same building. This incident has been very fully reported.*

Mr. E. Hill thinks that explosion might damage an installation. Whilst agreeing that this might happen, we have not yet come across any case on record where an electrical explosion has damaged a fire protective installation, and where this does happen the back-up appliances recommended should be brought into action.

Safety of Personnel

Mr. Milne discusses the question of the safety of personnel working where CO_2 has been installed, and he suggests that greater safety is obtained with an installation of the remote-controlled type on the ground that it ensures delay in the operation of the release valves until the control-room staff is satisfied that nobody would be endangered by the release of the gas.

We fear that such delay might defeat the object of the protective installation. The paper emphasizes that speed in application of any medium to an oil fire, or any other fire for that matter, is of vital importance. It cannot be overlooked that the safety of personnel is an equally important matter; as a safety measure we would prefer the local safety-pin method. Far quicker action can be expected from someone on the job than can be obtained even in the best circumstances from someone at a distance who has to act through the agency of a liaison of some kind or other.

Several speakers seem to fear the accidental tripping of mechanical operating wires by workmen, and prefer electrical detection on the ground that the conduit makes it safer. We agree with Mr. Richardson that in any installation put up by a reputable manufacturer all operating wires are protected by tube or in some other manner, and from the point of view of accidental operation are as safe as electrical systems.

Toxicity

Mr. Coates points out that the paper specifically mentions the toxic or lethal properties of fire-fighting media, without mentioning the lethal properties of the products of combustion. Although germane to the problem, it is rather outside the present scope, but we agree that too much emphasis cannot be laid on the danger of the products of combustion. Much work has been done on the toxic and lethal effects of individual gases, but, so far as we know, no work has been done on the physiological response to mixtures of gases found in products of combustion, or on whether the hyper-respiration caused by CO_2 may not cause larger intake of some of the poisonous gases that may be present after a fire. That some such phenomena occur is the only explanation that can be given to cases where death has occurred in a building at some distance from the actual seat of fire. This, again, emphasizes the necessity of thorough ventilation and the provision of breathing apparatus for use in emergency.

Mr. Eberhardie does not agree with the report published by the Chief Medical Officer of the London County Council, and uses the analogy of the toxic effects of water and of poison. The paper nowhere states that CO_2 is toxic, but it cannot be disputed that it may be lethal. Physiologically it produces drowning, and whether a man is poisoned or drowned the ultimate result is very much the same.

The publication from which Mr. Spicer quotes figures is presumably a report No. 2375 published by the American Underwriters Laboratories, but the figures he quotes are misleading, as the percentage given is considered on the hourly basis. The conclusions which Dr. Barclay draws from the figures he quotes differ from the conclusions drawn in that report, which state that the time factor is more important than the concentration. That they are misleading and inaccurate is borne out by the statement made by Mr. Kennedy on page 266, which we confirm. The answer is, of course, "What are the facts in practice?" And the investigator's experience of actual exposure, confirmed by Mr. Bellerby, shows that much that has been said about the toxic effects of methyl-bromide is exaggerated.

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* "The Detroit Fire School Explosion," *National Fire Protection Association Quarterly*, October, 1935.

Foam

Foam density.

Mr. Chadwick suggests that foam density can be varied during application, and mentions that this can be done with the Pyrene branch pipe. This is, of course, quite true, but with a permanent installation, particularly of the automatic type, the foam density should have a proper setting. Normally an installation of this type could easily be in operation for some time before anybody could reach it to adjust control valves, and even then such an operation could only be carried out by a trained operator.

Chemical versus Mechanical Foam.

Mr. Mellonie asks whether chemical or mechanical foam is the more effective. A simple distinction cannot be drawn between them, but the point was dealt with by Mr. Gilbert in the London discussion.

Water

Pressure.

Mr. Nimmo suggests that water should be available for 10 minutes at a pressure of 60 lb. per sq. in., but for the class of oil met with in electrical installations 50 lb. per sq. in. should give a sufficient margin of safety under all normal circumstances. Higher pressures are not considered necessary unless spirit fires are feared. In regard to the time, it is, of course, best to provide for the longest time possible, but 10 minutes' supply would seem to be impracticable in most cases.

Mr. Chisholm states that in Test 43 the fire was actually extinguished in 9 seconds, and in Test 44 in about 27 seconds. We confirm these figures. In the latter test the fire within the zone of protection was extinguished in the time given, and only the portion outside the zone of protection continued to burn. We cannot subscribe to the figure given by Mr. Chisholm of 16 lb. per sq. in. at the nozzles, as the only pressure measured was the gauge pressure at the feed point of the installation, and this pressure was 25–30 lb. per sq. in. In regard to the minimum pressure of 50 lb. per sq. in. at the projectors, quoted in the recommendations, it should be borne in mind that an extinguishing system of this nature is not comparable with a sprinkler installation used for a fire other than an oil fire. The sprinkler system, even if of inadequate pressure or volume, will provide some cooling effect upon the surroundings. On the other hand, the application of water to burning oil at a pressure and volume insufficient to extinguish the flames might well float the oil over a wide area and be the cause of spreading the fire.

Pressures of less than 50 lb. per sq. in. might extinguish fires, but in our opinion cannot be relied upon to provide that margin of safety which is necessary when dealing with a fire in practice, into which so many variables enter, and it is because it is felt that reliance on an installation running at pressures lower than this might prove to be living in a fool's paradise that the minimum of 50 lb. per sq. in. is recommended. In outdoor installations and in exposed positions it might even be desirable, according to local circumstances, to have even higher pressures. The pressures given refer, of course, to transformer-oil fires, and would be quite insufficient for dealing with spirit fires.

Safety of application.

Mr. Leach refers to the risk of damaging the insulation of indoor type switchgear by applying water. This is appreciated, and Recommendation B on page 734 refers to the question. The consequential effects of applying water may be serious, and in such installations there is much to be said for the use of inert gas.

Mr. King is correct in stating that experiments have been carried out in America with water sprayed from hand branch pipes played on to high-voltage conductors. Similar experiments have also been carried out in England and in France. Published results are, however, not in agreement and the E.R.A. has this question under consideration.

Mr. Leach refers to certain disadvantages of water installations and, in particular, to their reliance on electricity supply. Such reliance is not essential, as the water pressure can be boosted by petrol or diesel-engine installations or, what may be better still, by a storage tank maintained under pressure from a compressed-air cylinder. It is agreed that in some installations, where space is limited, the need for such equipment may rule out the use of water, and in such cases inert gas has certain advantages.

We agree that commissioning tests are desirable, but we cannot agree with Mr. Leach that they are impossible on site. The report recommends that all installations should be subject to commissioning tests, and we know of many instances where this is actually done as a matter of routine.

Hand branch pipes.

We cannot agree with Mr. Gilbert that manually applied water streams can only be applied by electrical experts, in view of the risk of shock. With a suitable spray nozzle it is probable that the heat would keep a fireman at an electrically safe distance. Research, however, is being carried out on this problem, and until the results are available the answer must remain a question of opinion.

Water solutions.

Mr. Chadwick suggests the use of a solution of bicarbonate of soda in fixed installations. If ordinary water is successful there does not appear much point in adding the complication of soda solutions. Furthermore, such solutions would have to be stored and have a tendency to creep and build up in nozzles, totally or partially blocking them. This disadvantage has often been pointed out in connection with the older types of soda-acid hand extinguisher.

Back-up hydrants.

It is unfortunate that Mr. Leach's sneaking regard for hydrants as a back-up protection has been destroyed. The first incident illustrated in the film is the perfect example of how not to use hydrants, and was included in the film for that very reason. The later incident in the film also using hydrants in the proper manner must have escaped his notice. The extinction by hydrant in this case was admittedly far from spectacular, but it was successful. Other tests not illustrated on the film were made with water from hydrants, with trained crews, and in these cases there were no failures.

Drainage

Mr. N. M. Hill, amongst others, inquires whether oil will go through chippings quickly enough to minimize the fire. In practice the use of granite chippings has proved effective, but such beds must be subjected to inspection and maintenance in the same way as any other part of the installation. The rate of drainage must be maintained. Pits should be kept free from grit, silt or soil, which clogs the interstices. This applies particularly to gritty or dusty regions and where pulverized fuel is used.

In regard to the question of draining the oil away from the transformer by means of a run-off and stop valve, there is no reason why this should not be very effective. It is true that the windings may sustain fire damage over a larger area as the burning surface drops, but once a fire starts in a transformer it usually means a total rewind anyhow. If this method is adopted, flame traps should be provided and care must be taken in locating the stop valve so that even in the event of a fire it is possible to approach near enough to operate it, otherwise the drainage system might just as well not be there.

Detection

Mr. Lambert refers to the use of smoke detectors, and we quite agree that smoke detection should be used as a method of indicating the presence of smoke but should not be used as a method of causing discharge. There may, of course, be some cases where the latter would be the better way of using smoke detectors, but these cases are few and depend upon local circumstances. Mr. McLean expresses surprise that more prominence has not been given to this question of smoke detection, but here again the object of investigation was the limitations and useful fields of application of fire-fighting media, and was not primarily intended to deal with smoke at all. Mr. Sharpe also agrees that smoke detection should be used as a warning rather than as a method of discharge.

Mr. Chisholm raises an interesting point in connection with fire alarms. He suggests that instead of having a general alarm, a selective alarm might be installed for each transformer. In our opinion this would be very useful. Normally the electrical protective gear would indicate the source of the trouble, but fires may be caused by many reasons other than electrical, and early indication of the position of the fire might save considerable damage.

Maintenance

Mr. Kerr mentions that no reference had been made to the maintenance of fire-fighting equipment, and whilst we thoroughly agree with him that this is so, the point was not dealt with in the recommendations as it did not form part of the investigation programme in hand.

We are rather inclined to agree with Mr. Sharpe that Mr. Chisholm is somewhat optimistic in thinking that cotton waste is never left lying about, and there are cases on record where combustible materials of this type have been the cause of the inception of fires in electrical and other installations.

Mr. Crocker asks whether it is dangerous to spread sawdust beneath transformers. In our opinion this does constitute a danger, as oily sawdust under certain conditions may cause a fire by spontaneous combustion. It may not be very likely that conditions in an electrical installation will favour spontaneous combustion, but the danger is there. One very large fire was caused by greasy paper from a canteen being blown under a hut, where it collected. Eventually the inevitable lighted cigarette end was also blown underneath, igniting the paper and setting fire to the hut. This fire spread so quickly that a nearby building became involved, resulting in one of the largest fires the electrical industry of this country has had to face. If one wishes to enhance appearance and neatness, why not use sand?

Mr. Dundas also emphasizes the importance of maintenance and regular inspection of fire protective installations, and mentions precautions against frost. Earlier this year the E.R.A. drew the attention of its members to precautions against frost and circulated a pamphlet giving guidance in this matter.*

Mr. Kennedy points out that all firms supplying automatic fire-extinguishing gear carry out regular inspections, and this is all to the good. The loophole that remains here is that the inspection staff of the manufacturer may not be acquainted with alterations or extensions to the layout. This point should always be borne in mind by the operating staff, and the fire-fighting installations should be reviewed as a whole when electrical alterations are made.

We agree with Mr. Kidd that it is imperative to modify fire protective installations to make them correspond to all modifications to the electrical installation.

Dwarf Walls

Mr. Crocker appears to suggest that pipes, etc., should not be mounted on barrier walls to avoid damage in case of an explosion. Pipes mounted on barrier walls are perhaps more liable to damage than pipes independently supported, but we feel that the risk of such damage is not great with a properly designed installation of walls and pipes. The design of dwarf walls must depend on local considerations, including the position and value, both monetary and electrical, of contiguous apparatus.

Col. Lyon wants dwarf walls to prevent oil projection in all circumstances. Such walls cease to be dwarf and become, in effect, barrier walls.

Mr. Kidd, however, objects to screens or barrier walls on three sides of a transformer. From a fire point of view, the provision of such barrier walls gives good protection, whereas for A.R.P. reasons we are advised to put in even four barriers where possible. In regard to the cooling of transformers, it has been held that the chimney effect produced by these walls helps rather than hinders the dissipation of heat. The question of ventilation requires special consideration in each case.

Obstructions Due to Installations

Mr. Spicer raises the question of obstruction caused by the pipework of the installations. Comparing the various installations put forward at Barking, it can be said at once that the installation of water pipes was made in such a manner that no obstruction was caused to the transformer itself. They were quite clear of its structure, except that in one case the top ring was placed a little low and would probably have fouled insulators had it been necessary to move the transformer. On the other hand, however, all the CO_2 installations put forward for the outdoor installation were such that a considerable amount of dismantling would have been necessary before the transformer could be moved. In the case of methyl bromide the pipework was also quite clear of the transformer, and would have required but little disturbance if the transformer were to be moved.

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* Ref. V/T9: "Precautions against Freezing of Fire Extinguishing Appliances."

Portable Equipment

The report stresses the advantage of rapid attack on the fire, and this is obviously best obtained by a fixed automatic installation. This undoubtedly adds to the cost of the fire-fighting equipment and in our opinion there are many small electrical installations involving oil-fire risks where it would not be economic to put in such an installation. Much depends upon the risk of fire spread, and the remarks on portable equipment are intended to help where automatic installations are not regarded as practicable. The recommendations were designed to encourage the use of fixed automatic equipment, and at the same time it was desired to point out that such installations should not be regarded as sufficient in themselves to cover vast areas, but that the use and installation of portable equipment should be encouraged for dealing with small fires not necessarily close to important equipment, but whose spread might involve danger areas. Mr. Dundas confirms this point of view.

Lubricating-Oil Risks

Mr. Longman refers to the risks incurred by the leakage of lubricating oil on to high-temperature steam pipes. This problem is more a question of prevention than protection. Experiments have been carried out with chlorinated lubricants on the Continent, but long-term experience is lacking. He refers also to the fires at Brussels and Portishead, and states that the common ingredient is oil. He does not mention the other even more important ingredient of inflammable material used in construction. Brussels, for instance, had a wood-lined roof and unprotected girders. The collapse of the roof was the real cause of the extensive damage, as it was also in a recent fire much nearer home.

Choice of Medium

Mr. Bellerby suggests that it would have been simpler to say "Study the local conditions, and whichever medium is considered suitable, see that it is properly applied." This is, in effect, what the paper does, but in addition it gives some guidance in the choice of media for given sets of conditions.

Types of Media Used

In reply to Mr. Leach, as shown in Table 9, Test No. 31 was the only one during which chemical foam was used. All other foam tests were made with mechanical foam.

The methyl bromide used in the tests was propelled by pure nitrogen. No account is taken of the nitrogen as a fire-extinguishing medium, and it in no way affects the efficiency of methyl bromide as an extinguisher. We know of no other propellant used in this country, except for a special purpose, when another reagent is definitely specified.

The principle of the use of carbon tetrachloride propelled by dry CO_2 was known to the investigating committee at the time when the test programme was under consideration. At least one firm interested in this method was invited to take part in the tests, but for some reason unknown to the committee no proposal to apply the system to the test plant was received. It was concluded that the interested persons did not consider any useful purpose would be served by putting up such an installation. In the absence of test experience, we cannot subscribe to the theory that screens would have been unnecessary with such a scheme. Screens were considered necessary to localize methyl bromide gas, which is heavier than carbon tetrachloride gas or CO_2, and it does not seem feasible that the lighter gases would be more self-localizing than the heavier ones.

Mr. Atack asks whether anything is known of a chemical which, if placed in an extinguisher, will extinguish incendiary bombs. During the course of the investigation many rumours of this nature cropped up, but no substance could ever be traced in such claim.

Fire Offices Committee

The Fire Offices Committee gave considerable help and co-operation to the Electrical Research Association, both before and during the tests. Lists of approved appliances may be obtained from the Committee.

THE SECONDARY CIRCUITS OF SYNCHRONOUS INDUCTION MOTORS*

By G. H. RAWCLIFFE, M.A., Associate Member.†

(*Paper first received 23rd August*, 1939, *and in revised form 8th January*, 1940.)

SUMMARY

The use of synchronous induction motors has steadily increased in the last 15 years, and much information about them is now contained piecemeal in various papers. No critical account of the various types of secondary circuit and of the ways of exciting them is yet available, however, and in the first part of this paper the author considers these systematically. The characteristics desirable are first elucidated, and each winding is then considered in the light of these characteristics. Their properties are finally summarized in tabular form.

The second part of the paper describes experiments by the author on the load reactance of synchronous induction motors. The relation between load and synchronous reactance for a machine with a barrel rotor is established practically, as is also the dependence of both these quantities on the secondary wave form. A correction for "magnetic backlash" is introduced.

The third part of the paper deals shortly with parasitic currents in secondary circuits, with oscillograms of these currents.

The appendices give mathematical results for secondary wave forms, ratings, starting torques and exciting currents. These results serve as standards with which actual results can be compared.

CONTENTS

(1) Introduction and General Principles. Pole Formation. Cascade Operation.
(2) Inversion of Synchronous Induction Motors.
(3) Objects of Winding Design.
(4) Fundamental Types of Secondary Winding.
(5) Derived Types of Secondary Winding.
(6) Load Reactance of Synchronous Induction Motors with different Methods of Excitation.
(7) High-frequency Alternating Currents in Secondary Circuits.
(8) Acknowledgments.
(9) Bibliography.
(10) Appendices. Some Mathematical Results.

(1) INTRODUCTION AND GENERAL PRINCIPLES

The principle of the S.I.M. (as it will hereafter be called) is well known. The machine starts as an induction motor with wound secondary, giving high starting torque, and when running at slightly subsynchronous speed d.c. excitation is applied to the secondary, and the machine pulls into step and can operate at various power factors by adjustment of the excitation. The secondary may be wound and excited in many ways, and these will now be considered.

Any a.c. machine must have equal numbers of poles on primary and secondary, but need not have equal numbers of phases. The supply, normally 3-phase, governs the primary, but 3-, 2-, or single-phase secondaries may all be used. "Straight" single-phase secondaries are, however, little used, since they tend to crawl at half speed[1] (see Appendix 3).

Pole Formation

The application of d.c. excitation to a polyphase winding is equivalent to stabilizing the alternating-current vectors in some particular position, so that the poles, instead of creeping round the winding, remain fixed with respect to it. By making the phases of unequal resistance any vector position could be chosen, but there is no advantage in an asymmetrical vector position and one of several symmetrical ones is commonly used. Method 12, Table 1, is a partial exception.

Cascade Operation

Two induction motors can be cascaded stator-rotor-rotor-stator, to run at a subsynchronous speed corresponding to the sum of the poles on both machines; the basic principles of this have been enunciated by Hunt.[1] The principles of cascade operation can be extended to S.I.M.'s and if alternating current is supplied to the first stator and direct current is fed into the second stator the set will pull into step as an S.I.M. The magnetizing current of the first machine is supplied through the interconnected rotors. An interesting modification of this principle is described by Schenfer.[2] Virtually, the two stators of such a cascade arrangement are superimposed and the two rotors amalgamated, the resultant rotor having a single-phase winding, since two equal, oppositely rotating, fields combine to give one pulsating field.

(2) INVERSION OF SYNCHRONOUS INDUCTION MOTORS

In an induction motor the primary carries both magnetizing and load currents, and is the more heavily loaded element in consequence. In an S.I.M. the *secondary* carries the magnetizing current and thus tends to become overloaded first. It is therefore common to use the stator with its larger winding space as the secondary and the rotor as the primary. This may give increased efficiency; Mulligan[3] quotes typical results. Hence the expression "secondary" is used, rather than "rotor," for generality.

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* The Papers Committee invite written communications, for consideration with a view to publication, on papers published in the *Journal* without being read at a meeting. Communications (except those from abroad) should reach the Secretary of The Institution not later than one month after publication of the paper to which they relate.

A shortened version, on which this paper is based, was read before the Mersey and North Wales (Liverpool) Centre, 3rd April, 1939.

† Liverpool University.

High-voltage machines are not inverted. Apart from the danger of rotating high-voltage windings, the primary of a high-voltage machine needs more insulation and may be more bulky than the secondary even though the latter is carrying the magnetizing current.

Further arguments for inversion are:—

(1) The secondary connections can be more readily changed at starting without multiplying slip-rings. The control gear is generally simplified.

(2) The secondary can be insulated for higher standstill voltages, thus reducing the exciting current.

(3) The secondary can be better impregnated to secure uniform heating; "gum" impregnation of rotors is impossible.

(4) The iron loss may be less when the rotor is the primary.

An interesting point in the design of inverted machines is that the brush spacing, as for rotary convertors,[4] must be such that the same part of the slip-ring does not always carry the peak primary current.

(3) OBJECTS OF WINDING DESIGN

These may be summarized as follows:—

(1) To obtain the highest possible (m.m.f./watts excitation) ratio. This reduces the exciter capacity and consequent secondary heating, and permits a longer air-gap. In Appendix 2 and Table 1 are shown comparative figures for various types of winding.

(2) To distribute the power loss as evenly as possible in the secondary. Only with equal currents in all phase bands will the heating be uniform.

(3) To obtain a sinusoidally distributed m.m.f.

(4) To make the winding easy to construct mechanically.

(5) To use materials economically: the minimum of copper and the iron at maximum magnetic loading. The temperature limit should be reached simultaneously throughout the machine.

(6) To cause damping currents to be generated if the load pulsates. The low-resistance secondary acts also as a damping winding in S.I.M.'s.

(7) To permit temporary induction operation if the maximum synchronous torque is exceeded.

(8) To keep the secondary standstill voltage to reasonable values.

(9) To minimize the amount of control gear.

(10) To give satisfactory starting as an induction motor. The properties of each winding in these respects are summarized in Table 1.

(a) M.M.F. Necessary

The m.m.f. is governed almost entirely by the air-gap length. A longer gap means a smaller ampere-turn ratio and a "stiffer" machine, with larger overload capacity, and less variation of power factor with load: on the other hand it reduces the efficiency and rating and increases the wattless kvA at starting. To obtain high overload capacity and uniform power factor, with a small air-gap, systems of variable automatic excitation have been employed.[5] The exciter is provided with an extra field winding fed from the secondary of a series transformer through a metal rectifier: the transformer primary carries one phase of the load current. The excitation thus varies automatically with load, giving constant power factor and higher overload capacity.

(b) Distribution of Heating in the Secondary

It is impossible to be precise about this. Non-uniform generation of heat will be of prime importance if the thermal conductivity of the secondary insulation is low; if it is high, uneven generation will be nearly smoothed out. Hoseason[6] considers that the temperature drop in electrical machinery from the "hot spot" to the external air should be divided into three stages: (1) "hot spot" to winding surface, (2) winding surface to cooling air, (3) cooling air to ambient air. Uneven heat generation will be felt in stage (1), and such improvements as tighter packing and better impregnation of the secondary will reduce the ill-effects of uneven heat generation. Stators can be better impregnated than rotors, semi-fluid "gums" not being permissible on rotors, and this, as stated, is an additional argument for "inversion."

(c) Sinusoidally Distributed M.M.F.

The supply voltage will be nearly sinusoidal, and the back e.m.f. must therefore be as similar as possible. Any harmonic components are at best wasteful and at worst harmful. Harmonics in the secondary flux may generate harmonic voltages which will circulate parasitic currents in the primary, though various arrangements of the primary are available to eliminate harmonic voltages. For example, two-thirds chording will eliminate phase 3rd harmonics, and star connection line 3rd harmonics, in a 3-phase winding. The (leakage) impedance presented by the primary to any harmonic currents will rise with the order of harmonic, as will any impedance in the primary supply itself. A quiet machine especially will require to have a sinusoidally distributed secondary.

(d) Mechanical Construction of Winding

In general the same considerations apply here as to the induction motor. Any modification which reduces the length of end-connectors will increase the efficiency and rating, and, for example, Method 12 (Table 1) gives a winding which can be wound concentrically for an odd number of pole-pairs without employing either three "tiers" of end connections or a skew coil and two tiers, all the exciting coils being in one layer. Method 17 will similarly be easy to construct.

(e) Economy in Materials

This will be increased if the slots in the secondary are of unequal width. The greatest flux density in the secondary occurs midway between the phase bands which carry the maximum direct current. It is thus permissible to alter the slot widths to correspond to the currents normally carried in the slots. An objection to doing so is that the normal punching machine produces equal slots equally spaced, and any departure from this would be costly.

(f) Self-damping Properties

All synchronous machinery may "hunt" on pulsating loads, and salient-pole machines are therefore fitted with

Table 1—Summary of Methods of Winding and Exciting Synchronous Induction Motors

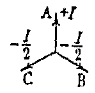
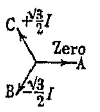
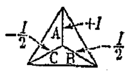
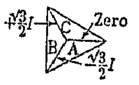
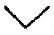
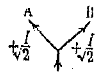
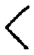
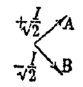
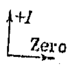
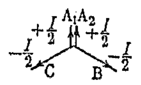
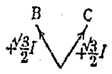
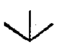
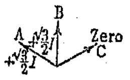
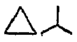
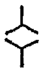
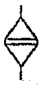
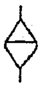
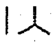
Method No.	Type of Secondary	Method of applying d.c. excitation	Corresponding a.c. vectors and phase currents	Maximum secondary current (1)	Effective secondary resistance (2)	Exciter volts	Excitation watts	Relative heat distribution in phases. See Section 3 (*b*)	Maximum value of fundamental component of m.m.f. in ampere-turns. See Appendix 1
1	3-phase star	Phase A in series with phases B and C paralleled. Fig. 5 and Section 4 (*a*)		I_3	$\frac{3}{2}R_3$	$\frac{3}{2}R_3I_3$	$\frac{3}{2}R_3I_3^2$	$1:\frac{1}{4}:\frac{1}{4}$	Fig. 9 and Apps. 1 and 4 $\frac{9}{\pi^2}I_3n_3$
2	3-phase star	Phase A isolated, or omitted. Phases B and C in series. Fig. 6 and Sections 4 (*a*) and 5 (*b*)	 C $+\frac{\sqrt{3}}{2}I$ Zero A B $-\frac{\sqrt{3}}{2}I$	$\frac{\sqrt{3}}{2}I_3$	$2R_3$	$\sqrt{3}R_3I_3$	$\frac{3}{2}R_3I_3^2$	$\frac{3}{4}:\frac{3}{4}:0$	Fig. 10 and Apps. 1 and 4 $\frac{9}{\pi^2}I_3n_3$
3	3-phase delta	Fed from one corner of delta to another. Third corner isolated. Fig. 7 and Section 4 (*a*)		$\frac{3}{2}I_3$	$\frac{2}{3}R_3$	R_3I_3	$\frac{3}{2}R_3I_3^2$	$1:\frac{1}{4}:\frac{1}{4}$	Fig. 9 and App. 1 $\frac{9}{\pi^2}I_3n_3$
4	3-phase delta	Fed from one corner of delta to the two others joined. One phase thus carries no current. Fig. 8	 $+\frac{\sqrt{3}}{2}I$ C Zero B A $-\frac{\sqrt{3}}{2}I$	$\sqrt{3}I_3$	$\frac{1}{2}R_3$	$\frac{\sqrt{3}}{2}R_3I_3$	$\frac{3}{2}R_3I_3^2$	$\frac{3}{4}:\frac{3}{4}:0$	Fig. 10 and App. 1 $\frac{9}{\pi^2}I_3n_3$
5	2-phase 3-wire (parallel fed) 	Fed from the common lead to the other two leads joined. Fig. 11 and Section 4 (*b*)		$\sqrt{2}I_2$	$\frac{R_2}{2}$	$\frac{R_2I_2}{\sqrt{2}}$	$I_2^2R^2$	$\frac{1}{2}:\frac{1}{2}$	Fig. 14 and App. 1 $\frac{8}{\sqrt{2}\pi^2}I_2n_2$
6	2-phase 3-wire (series fed) 	Common lead isolated. Fed from one lead to the other. Fig. 12 and Section 4 (*b*)		$\frac{I_2}{\sqrt{2}}$	$2R_2$	$\sqrt{2}I_2R_2$	$I_2^2R_2$	$\frac{1}{2}:\frac{1}{2}$	Fig. 14 and App. 1 $\frac{8}{\sqrt{2}\pi^2}I_2n_2$
7	2-phase 3-wire (one phase fed)	Fed from common lead to one other lead. See Section 4 (*b*). Third lead isolated, or phase omitted. Fig. 13		I_2	R_2	I_2R_2	$I_2^2R_2$	$1:0$	Fig. 15 and App. 1 $\frac{8}{\sqrt{2}\pi^2}I_2n_2$
8	3-phase star (one phase wound double)	The 2 bands of double-wound phase in parallel, in series with the other 2 phases paralleled. Section 5 (*a*)	 A_1A_2 $+\frac{I}{2}$ $+\frac{I}{2}$ $-\frac{I}{2}$ C B $-\frac{I}{2}$	I_3	$\frac{4}{3}R_3$	$\frac{4}{3}I_3R_3$	$\frac{4}{3}I_3^2R_3$	$\frac{1}{3}:\frac{1}{3}:\frac{1}{3}:\frac{1}{3}$	Figs. 16 and 17 and App. 1 $\frac{8}{\pi^2}I_3n_3$
9	3-phase V-connected	Two phases at 60° fed in parallel. Third phase isolated or omitted. Section 5 (*b*)		$\sqrt{3}I_3$	$\frac{R_3}{2}$	$\frac{\sqrt{3}}{2}I_3R_3$	$\frac{3}{2}I_3^2R_5$	$\frac{3}{4}:\frac{3}{4}:0$	$\frac{9}{\pi^2}I_3n_3$
10	3-phase double V-connected 	Two phases at 60° in parallel. Third phase shorted on itself. Section 5 (*b*)	 B A $+\frac{\sqrt{3}}{2}I$ $+\frac{\sqrt{3}}{2}I$ Zero C	$\sqrt{3}I_3$	$\frac{R_3}{2}$	$\frac{\sqrt{3}}{2}I_3R_3$	$\frac{3}{2}I_3^2R_3$	$\frac{3}{4}:\frac{3}{4}:0$	$\frac{9}{\pi^2}I_3n_3$
11	3-phase star	As 2, but phase A wound and shorted on itself. Section 5 (*b*)	As 2	$\frac{\sqrt{3}}{2}I_3$	$2R_3$	$\sqrt{3}I_3R_3$	$\frac{3}{2}I_3^2R_3$	$\frac{3}{4}:\frac{3}{4}:0$	$\frac{9}{\pi^2}I_3n_3$
12	3-phase unsymmetrical star	Connections as 1, but, owing to high resistance of one phase, acts as method 2. Section 5(*b*)	Nearly as 2. See Fig. 18	(nearly) $\frac{\sqrt{3}}{2}I_3$	(nearly) $2R_3$	(nearly) $\sqrt{3}I_3R_3$	(nearly) $\frac{3}{2}I_3^2R_3$	(nearly) $\frac{3}{4}:\frac{3}{4}:0$	(nearly) $\frac{9}{\pi^2}I_3n_3$
13	3-phase delta-star 	Connected as 4 to start and 1 to run: acts exactly as method 1. Section 4 (*a*)	As 1	I_3	$\frac{3}{2}R_3$	$\frac{3}{2}I_3R_3$	$\frac{3}{2}I_3^2R_3$	$1:\frac{1}{4}:\frac{1}{4}$	$\frac{9}{\pi^2}I_3n_3$
14	3-phase double star 	As 1, but half winding commonly "reversed" to be "image" of the other. Fig. 4	As 1	If a star winding as 1 is divided into two separate stars each with the same turns/phase and half the gauge of the original star, the exciting current of 1 is halved, and the volts doubled, series connected				As 1	As 1, where n_3 is taken as total turns in both halves
15	3-phase double delta 	As 4, but half winding commonly "reversed" to be "image" of the other	As 4	A delta winding as 4 may be split into two parts in the same way, and for the same objects, as the split star No. 14				As 4	As 4, where n_3 is turns in both halves of winding. $\sqrt{3}I_3$ is total external current
16	3-phase double delta 	As 15, but phase carrying no d.c. current omitted in either one or both halves of winding	As 4	As 15				As 4	As 15
17	2-phase 4-wire	As 7, one phase only excited; the other shorted on itself. Exciter inserted between phases. Fig. 19	As 7	I_2	less than R_2	less than I_2R_2	less than $I_2^2R_2$	—	The m.m.f. for given watts is much greater than in 7 because of heavier winding of exciting phase. Fig. 15
18	1-phase excitation. Separate 3-phase star starting winding 	Excited single-phase exactly as synchronous motor. Section 5 (*e*)	—	—	—	—	—	Uniform in excitation winding	App. 2

Table 1—*continued*

Starting properties. See Section 3 (*h*)	Damping properties. See Section 3 (*f*)	Induction action on synchronous overload. See Section 3 (*g*)	Control gear and number of secondary leads. See Section (3)	Notes	Extent of use
Normal induction action. O.C. volts higher than delta in ratio $\sqrt{3}$.	Good. Additive damping voltages in phases B and C. Damping current in these phases and in link between B and C. Fig. 1	Good. Normal induction action—one phase current passes through exciter	Three leads. Exciter field rheo. and starter interlocks, only, with exciter always connected. Single-pole double-throw switch to isolate exciter	Method described by the inventor, Danielson. Exciter may be left permanently in circuit on small machines	Very widely; especially on smaller machines
Poor without connection of machine and starter "star" points. Satisfactory if this is done. App. 3 and Fig. 29	Poor. Equal opposed voltages in B and C. Fig. 2. No damping current at small displacements	On load star point cannot be brought out; winding is effectively single phase and gives rather poor induction action. App. 3	Two leads for excitation. One extra to interconnect "star" points	Liable to hunt when synchronizing owing to poor damping. Minimum (three-phase) excitation current. App. 4	Frequently; especially on very steady drives
Normal induction action. Low O.C. secondary voltage	Poor. Damping volts in phases B and C opposed. No damping volts in phase A	On-load winding is effectively single-phase as No. 2. App. 3	Double-pole double-throw switch to isolate exciter		Little used
Normal induction action if all phases wound. If one phase omitted less satisfactory, but usually tolerable	Some damping volts, additive, in phases B and C. Excellent damping with phase A wound	Good. Normal induction action. One line current passes through exciter	Exciter may be left in circuit as in 1. Three leads. Single-pole double-throw switch to isolate exciter	Phase carrying no current sometimes omitted, or reduced in section. Section 5 (*c*)	Used mainly in modifications. See 9, 10, 13, 15 and 16
Normal induction action	Good. Additive damping voltages round the closed circuit of the two phases	Normal induction action; both phase currents through exciter	Exciter may be left in circuit	Uniform heating in 2-phase arrangement is advantage over 3-phase. M.M.F. waveforms less nearly sinusoidal in 2-phase arrangements	At one time considerably; less of late
As 5	Poor. Opposed damping volts in 2 phases. No damping current	Effectively a single-phase winding when excited with d.c. Poor induction action		As 5, from heating aspect—but damping so poor that reduced exciting current does not outweigh this	Seldom used
As 5, with both phases wound. Bad with only one phase wound. App. 3	Very poor with one phase isolated. Excellent with this shorted on itself. See 17	Poor, using only one phase. Otherwise as 17	Two, theoretically. Actually an unpractical case		Not at all as it stands. Modified as 17, considerably
Satisfactory but some asymmetry. Generally only half double-wound phase used in starting	Good. Damping volts round all 4 phase bands in series	Fair; some asymmetry. Circulating current round 2 parallel phase bands	Four leads normal	M.M.F. waveform as 2-phase systems	To some extent, especially abroad
Neutrals of machine and starter to be interconnected for satisfactory starting. As 2, but reduced standstill volts	Good. Damping volts in each phase, same polarity and phases in parallel	Fair. App. 3	Three leads without phase reversal; four with reversal. Three-pole double-throw switch to reverse phase and isolate exciter or starter	This connection may be used for starting only—then one phase reversed to give arrangement 2 for excitation	With some frequency
Neutrals connected as 9, but better starting torque	Excellent, as 9, and additional damping from shorted phase	Satisfactory, but twice phase current in neutral	Four leads	Phase shorted may be wound with thinner gauge wire	By some Continental makers
Normal induction action	Excellent; shorted phase is at points of maximum flux	Much better than 2. Still some asymmetry	Four leads	Phase shorted may be wound with thinner gauge wire	Considerably, especially abroad
Satisfactory. Normal type induction motor starter used	Excellent, since damping winding is at points of maximum field flux. Fig. 3	Satisfactory induction action. Secondary volts between leads are balanced	As 1. Exciter usually left in circuit. Minimum of control gear	Combines many advantages of methods 1 and 2. Short chording (Sections 3 and 5 (*b*)) economizes copper. Fig. 18	One maker's patent
Good, as No. 4. Used to keep down secondary O.C. volts at standstill	Good, as 1	Good, as 1	Much complicated control gear. Six leads		Occasionally on very large machines
Commonly one star, only, used for starting: alternatively both in parallel. Normal induction action	Good. Either as No. 1 in each separate star, or in same 4 phase bands in series, depending on connections. Fig. 4	Good, as 1	Six leads. Stars connected series for synchronous operation	Care needed in joining two stars. Excitation may be correct, yet damping voltages in two stars may cancel	On large machines
Commonly one delta, only, used for starting: alternatively both in parallel. Normal induction action	Good	Good, as 4	Six leads	Care in interconnection, as in 14, to avoid cancelling damping voltages. Section 5 (*c*)	On large machines
Complete deta, only, used for starting. If neither half complete, starting adversely affected	Good, unless one phase omitted from both halves of winding. Then only fair. Compare 4	Good, unless one phase omitted from both halves of winding. Compare 4	Six leads	Phase carrying no current may be reduced in section. Section 5 (*c*)	Occasionally in lieu of 15
Maximum standstill volts to earth that of one phase. Normal induction starting	Excellent; since damping winding situated at points of maximum field flux. Sections 3 (*d*) and 5 (*d*)	Normal induction action, but since phases may be unequal some unbalance may occur	Four leads. Exciter permanently in circuit, usually. Three pole double-throw switch to isolate exciter	Phase for excitation much more heavily wound than damping phase. Exciter earthed. Turns/phase may differ	Considerably. One maker's patent
Normal induction starting. Exciting winding may have to be shorted through resistance to avoid high O.C. volts	The starting winding acts also as damping winding in same way as Method 1	Good. Normal induction action in starting winding	Five leads. May be reduced to four by joining one end of both running and starting windings together	Table 2 and App. 2	Increasingly common; on large machines especially

a separate damping winding. One advantage of the S.I.M. is that the low resistance of the secondary permits its use both as an exciting and as a damping winding. These purposes are, however, mutually exclusive, and the part of a winding which is most effective as a damper is least effective as a magnetizing winding. The ideal damper is situated at the points of maximum field flux; the most effective magnetizing winding at points of zero flux.

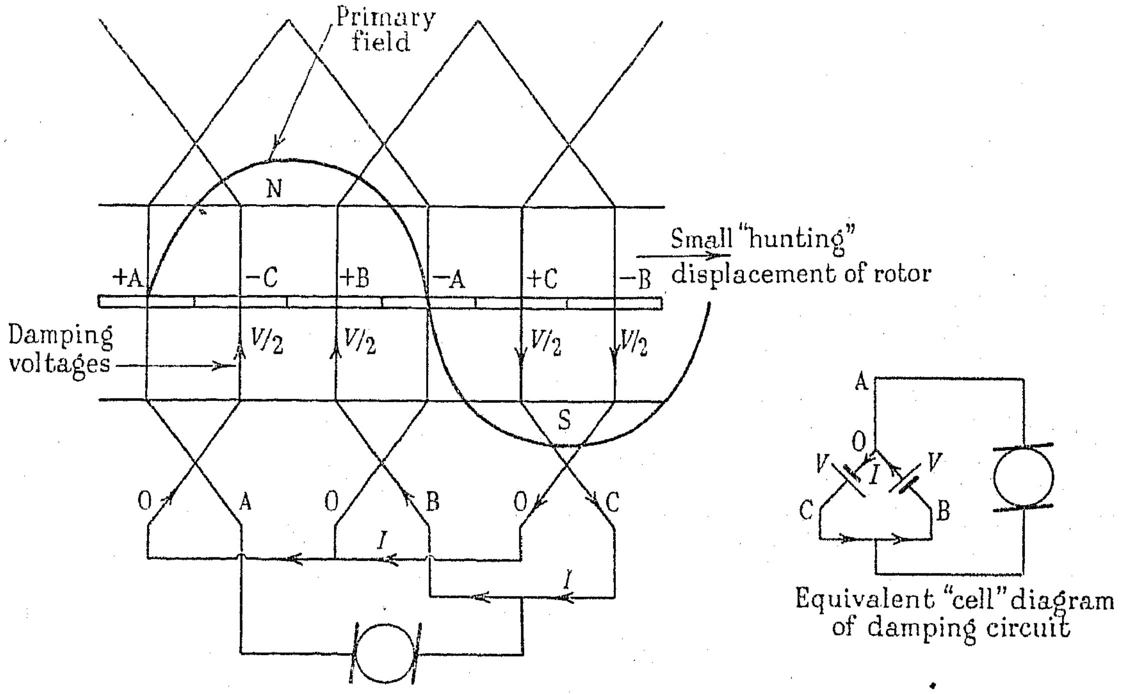

Primary field
N
S
Small "hunting" displacement of rotor
+A
−C
+B
−A
+C
−B
Damping voltages
V/2
V/2
V/2
V/2
O
A
O
B
O
C
I
I
A
O
V
I
V
C
B
Equivalent "cell" diagram of damping circuit

Fig. 1.—Damping of S.I.M. with method of excitation as in Fig. 5.

As the secondary moves relatively to the primary field, owing to pulsation of load, extra voltages are induced in all phases of the secondary which may assist or oppose one another according to the winding. If they assist one another in a closed path (which may include the exciter armature) currents will be induced in the secondary which tend to damp out the pulsations.

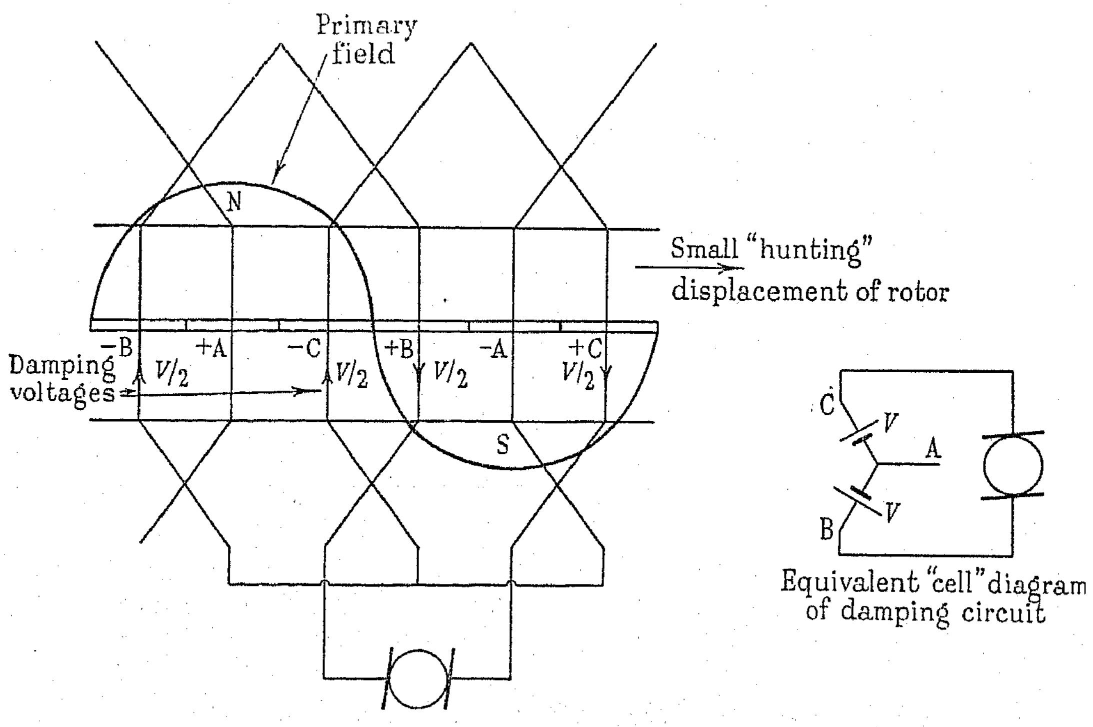

Primary field
N
S
Small "hunting" displacement of rotor
−B
+A
−C
+B
−A
+C
Damping voltages
V/2
V/2
V/2
V/2
C
V
A
B
V
Equivalent "cell" diagram of damping circuit

Fig. 2.—Damping of S.I.M. with secondary winding as in Fig. 6.

The damping properties of a winding may be examined by constructing diagrams similar to Figs. 1, 2 and 3. Figs. 1 and 3 represent windings with natural damping properties; Fig. 2 a winding without them. The results for every type of winding are shown in Table 1. It will be seen that where phases are fed in parallel the damping is satisfactory, but in series not so.

The " equivalent cell " diagram is a convenient device to show the seat of the damping voltage and the path of the damping current. The " polarities " and " current directions " are conventional. Further, for a given small displacement of the rotor the polarity depends on whether the primary is the stator or rotor.

To reduce the secondary standstill voltage each phase band may be wound in two halves. Either one half alone is used for starting, or both halves in parallel: the

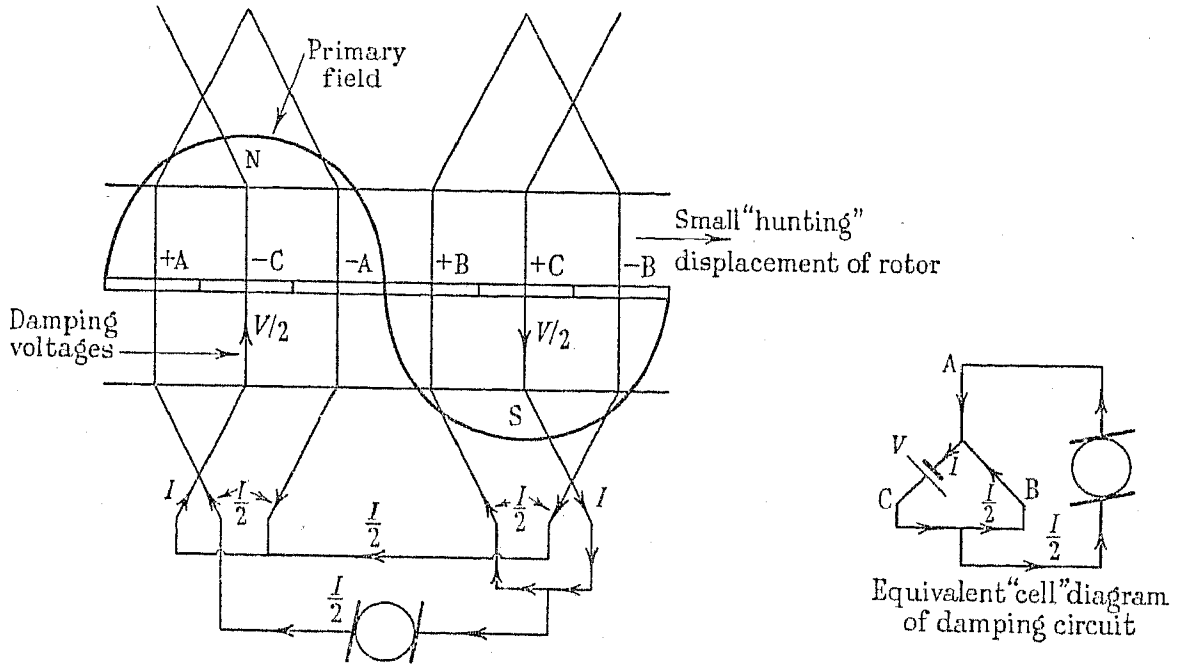

Primary field
N
Small "hunting" displacement of rotor
+A
−C
−A
+B
+C
−B
Damping voltages
V/2
V/2
S
I
I/2
I/2
I/2
I
I/2
A
V
I
C
B
I/2
I/2
Equivalent "cell" diagram of damping circuit

Fig. 3.—Damping of S.I.M. with secondary as in Fig. 18.

two are connected in series for running.[7] The interconnection must be so made that the damping voltages in both halves are cumulative and not opposed. Fig. 4 shows a series star arrangement. It is common, as shown, to reverse one star so that it is the "image" of the other, each phase band being reversed. For excitation it would be sufficient only to connect C_1E_0 and B_1F_0, but this would give no damping, the relative polarities of the damping voltages being shown in Fig. 4.

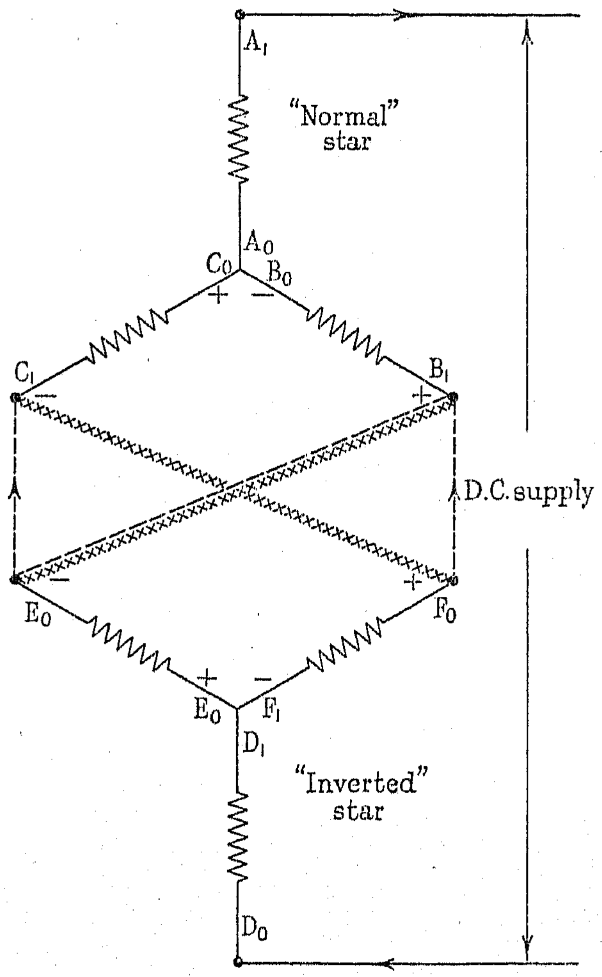


Fig. 4.—Interconnection of 2 stars in series, both methods to give adequate self-damping.

Stars interconnected either by 3 ——— lines or by 2 × × × lines. Signs show instantaneous damping voltages.

For damping B_1E_0 (*or* C_1F_0) must also be connected. Alternatively B_1E_0 and C_1F_0 alone may be connected.

Series delta connections (Methods 15 and 16, Table 1) may also be employed and similar arguments apply.

(g) Short-time Induction Operation

The pull-out torque of an S.I.M., if used as an induction motor, is usually higher than that when used as a synchronous motor. It is therefore best to use a winding which leaves the secondary connected (apart from the insertion of the exciter) as it would be connected for induction operation. If a peak load occurs the machine may work for an instant as an induction motor and return to synchronism after the peak. The induction action is unsteady, due to the superimposed synchronous torque, but it is permissible for a brief period. Any secondary winding will give some induction torque, but a winding connected as for normal induction operation is ideal. All windings, except the fundamental methods 1–7 (Table 1), share the disadvantage that if the exciter fails the whole set is out of commission and cannot be run as an induction motor until the exciter is repaired. The more the winding differs from an induction motor the greater the number of special S.I.M. parts, which complicates manufacture.

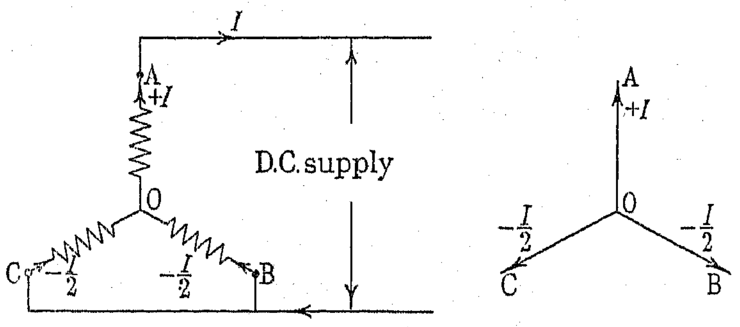


Fig. 5.—Method 1 of forming d.c. poles on 3-phase star rotor, and corresponding a.c. vectors.

(h) Secondary Standstill Voltage

Every S.I.M. needs lower exciting voltage and higher exciting current than the corresponding synchronous motor. The power ratings of exciter, leads, brushes, etc., fall as the current rises and it is thus desirable to raise the exciting voltage as far as possible. Also, the possibility of exciter instability is reduced with increasing exciter voltage. This necessitates winding the secondary with more turns of thinner " wire " (the power loss for a given m.m.f. is independent of " wire " size, assuming constant winding space and " copper factor "). The objection to doing so is that the secondary standstill voltage rises proportionally.

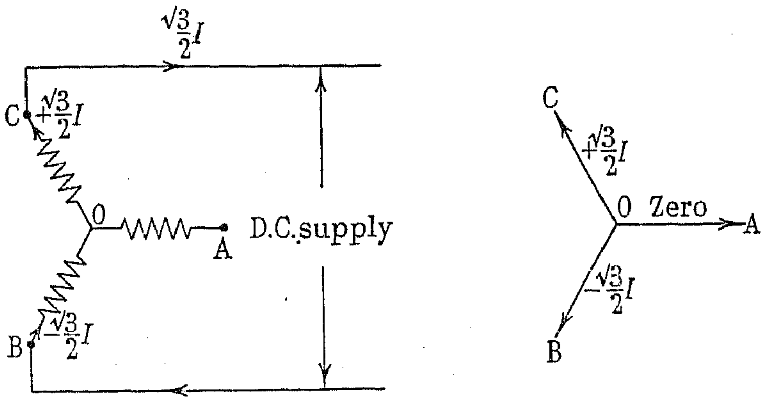


Fig. 6.—Method 2 of forming d.c. poles on 3-phase star rotor, and corresponding a.c. vectors.

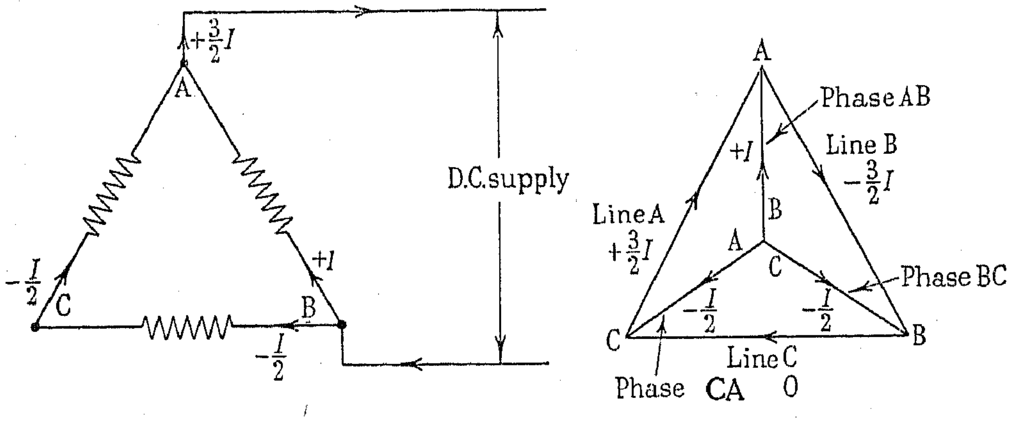


Fig. 7.—Method 3 of forming d.c. poles on 3-phase delta rotor, and corresponding a.c. vectors.

Several methods have been used to deal with this difficulty:—

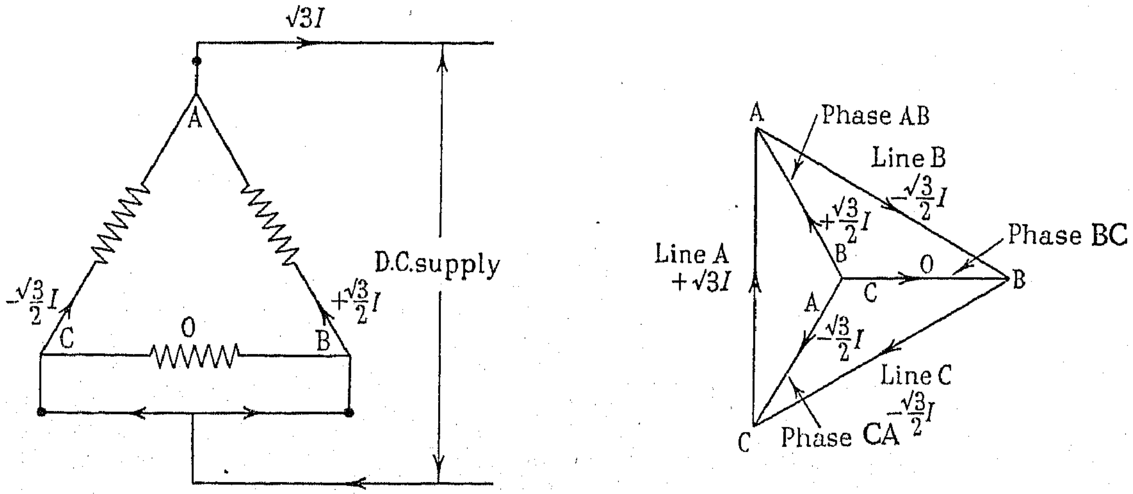


Fig. 8.—Method 4 of forming d.c. poles on 3-phase delta rotor, and corresponding a.c. vectors.

(1) Parallel-series windings, connected parallel-start, series-run. Alternatively, only half the winding may be used when starting. Carr[7] describes parallel-series windings in detail. (Methods 14, 15 and 16, Table 1.)

(2) Three-phase windings connected delta-start, star-run. (Method 13, Table 1.)

(3) " V " connection of phases. (Method 9, Table 1.)

(4) The voltage to earth may be minimized by an earth at the proper point in the secondary winding [see Section 5(*d*)]. An earth is especially needed when the exciter is left permanently in circuit, since the exciter armature is the least insulated part of the secondary circuit.

All these devices are more easily applied on inverted machines.

(4) FUNDAMENTAL TYPES OF SECONDARY WINDING

(a) Three-phase Secondaries

The four fundamental methods of exciting 3-phase secondaries, two star and two delta, are shown in Figs. 5, 6, 7 and 8. The corresponding m.m.f. wave forms are shown in Figs. 9 and 10, and the Fourier analyses in Appendix 1. Most 3-phase types of winding can be derived from one of these fundamental types. Fig. 5 shows the original arrangement used by Danielson,[8] which is still popular. It will be seen from Appendix A that these 4 methods give the same m.m.f. for the same excitation power: though the current and voltage vary widely, their product is constant. No first-order economy can be effected by choice of connections but, as explained in Section 3(*g*), the lowest current alternative is best on grounds of rating. The only advantage which a delta winding possesses over the same winding star-connected is the reduced secondary standstill voltage, and delta-star switching arrangements have been used (Method **13**, Table 1).

(b) Two-phase Secondaries

Fundamental 2-phase 3-wire secondaries are shown in Figs. 11, 12 and 13. The corresponding m.m.f. wave

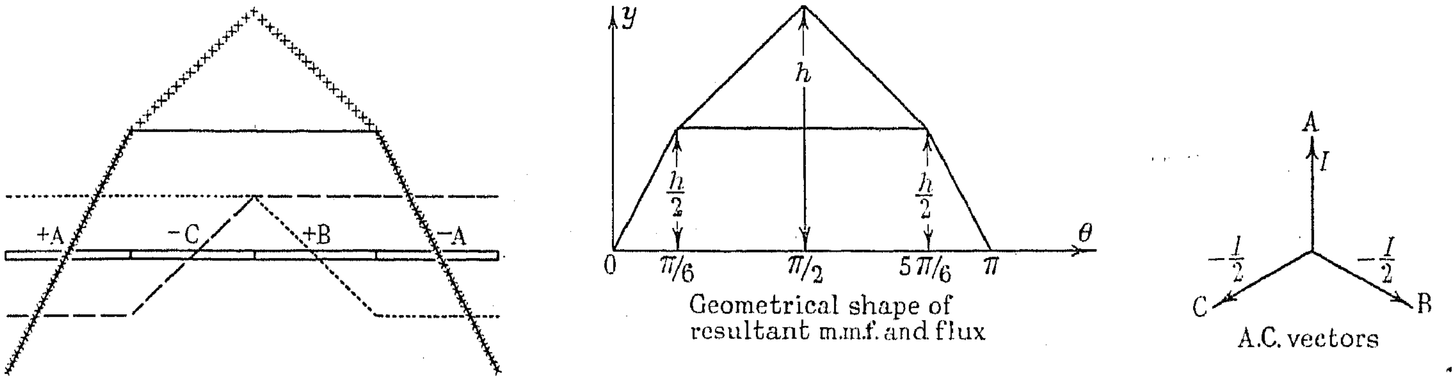


Fig. 9.—M.M.F. from excitation as in Figs. 5 and 7 (3-phase).

M.M.F. due to phase A ———— M.M.F. due to phase C — — — —
M.M.F. due to phase B .... Resultant m.m.f. × × × × ×
(The signs refer to winding directions).

forms are shown in Figs. 14 and 15, and the Fourier analyses in Appendix 1. A comparison of the m.m.f./watts ratio for 3- and 2-phase windings is given in Appendix 2.

(5) DERIVED TYPES OF SECONDARY WINDING

(a) Double-wound Third Phase, Star

The inequality of heat distribution in Method 1 has been modified[9] by winding 2 equal paths in parallel for the phase which carries the full current, making 4 phase bands per pole. This gives uniform heating and an m.m.f. wave form as shown in Fig. 16. Fig. 17 shows that this produces the same m.m.f. as a 2-phase parallel-fed system and that the same winding can (theoretically) be connected for either system of excitation. The 2-phase system, however, requires twice the exciting current and half the voltage. Since (see Appendix 2) the 2-phase system is less efficient than the 3-phase, a certain amount of m.m.f. is sacrificed by spreading the heat more evenly. Some increase in m.m.f. can be obtained by adjustment of slot position and size, but there are manufacturing objections to this.

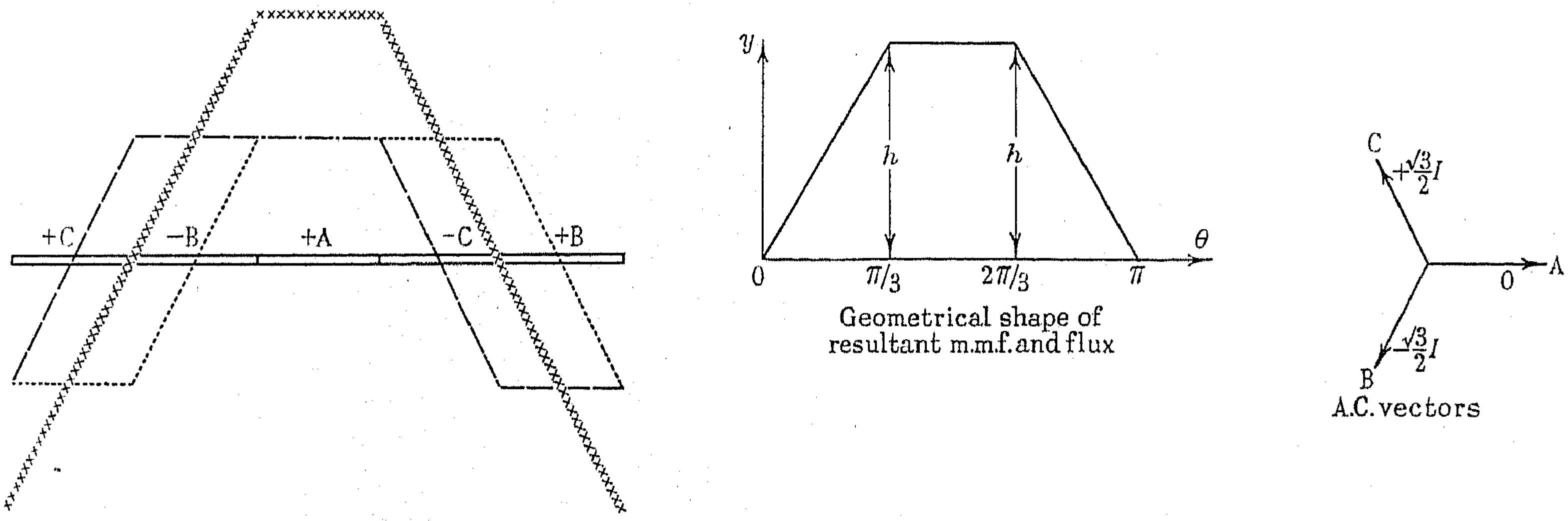


Fig. 10.—M.M.F. from excitation as in Figs. 6 and 8 (3-phase).

M.M.F. due to phase B ....
M.M.F. due to phase C — — — —
Resultant m.m.f. × × × × ×
(The signs refer to winding directions).

This winding gives some asymmetry at starting, the phase bands being situated at 0°, 180° and 270°—the first band being of double width. The two halves of the first band should not be paralleled during starting or there will be heavy circulating currents: either one half only is used, or the two halves in series. The first alternative needs 4 secondary leads, the latter 6, but it may start more smoothly.

(b) Three-phase Star—Two Phases used for Excitation

Only two phases may be wound and used for starting and excitation as Method 2 (Table 1). The starting properties are considerably improved by interconnecting the neutrals of winding and starter, otherwise the winding is virtually single-phase (Appendix 3). Alternatively, V (60°) connection of the 2 phases may be employed at starting to reduce the secondary standstill voltage, one phase being afterwards reversed. In neither case is it possible to maintain the neutral connection during

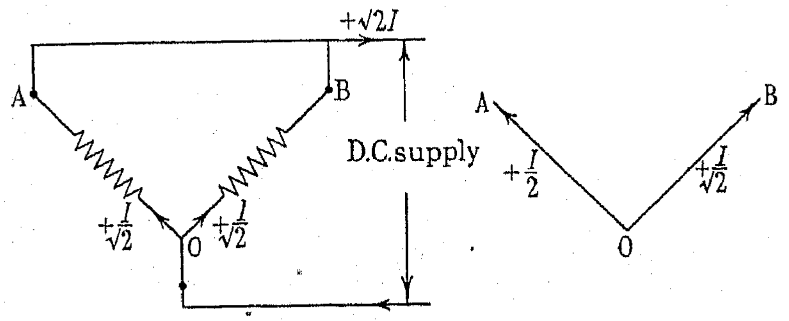


Fig. 11.—Method 5 of forming d.c. poles on 2-phase (parallel-fed) rotor, and corresponding a.c. vectors.

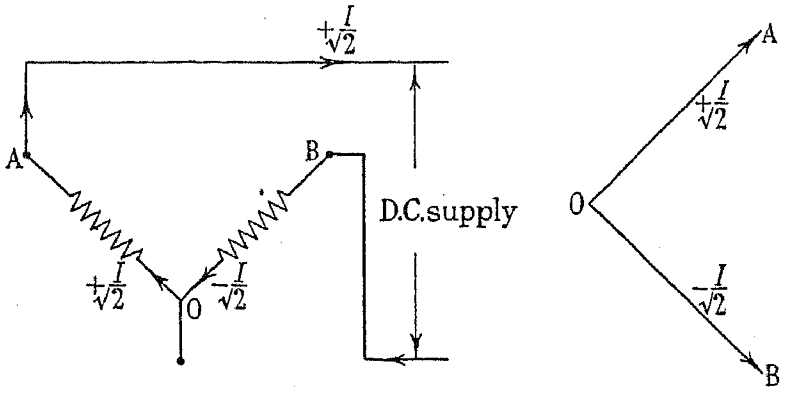


Fig. 12.—Method 6 of forming d.c. poles on 2-phase (series-fed) rotor, and corresponding a.c. vectors.

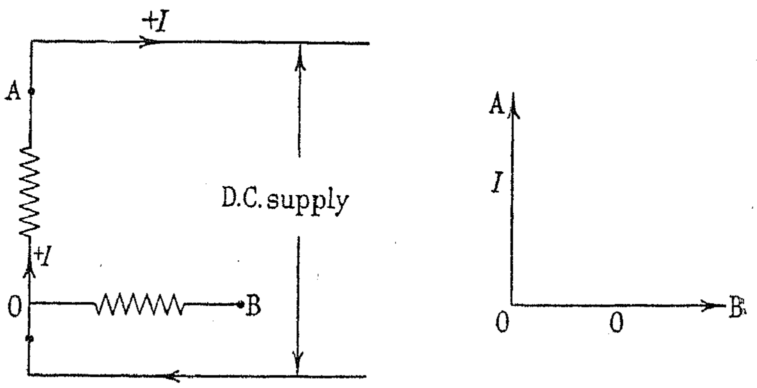


Fig. 13.—Method 7 of forming d.c. poles on 2-phase rotor, and corresponding a.c. vectors.

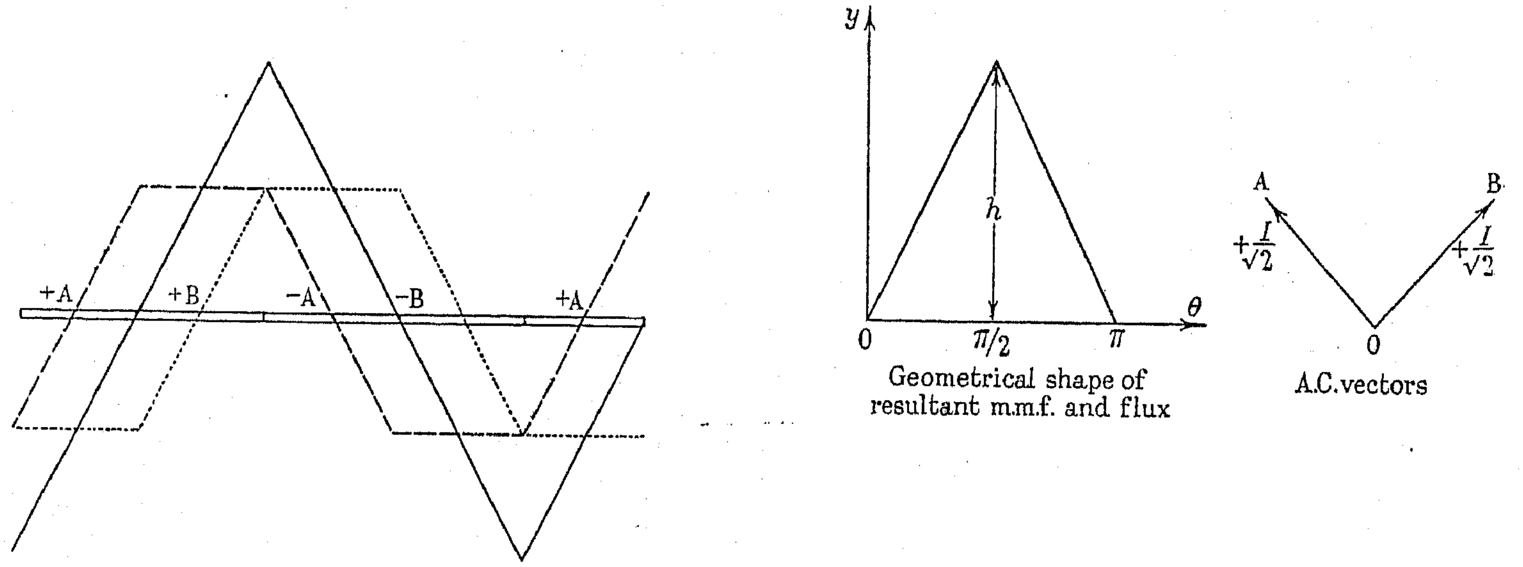


Fig. 14.—M.M.F. from excitation as in Fig. 11 (2-phase). M.M.F. of Fig. 12 similar, but displaced 90 electrical degrees.

M.M.F. due to phase A — — — —
M.M.F. due to phase B ....
Resultant m.m.f. ————
(The signs refer to winding directions).

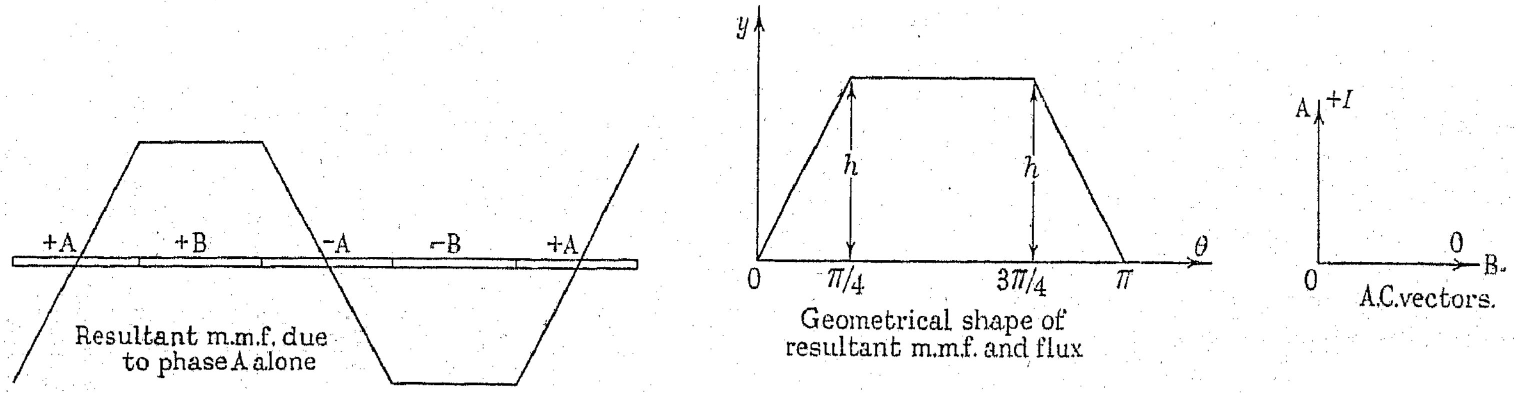

+A
+B
−A
−B
+A
Resultant m.m.f. due to phase A alone
y
h
h
θ
0
π/4
3π/4
π
Geometrical shape of resultant m.m.f. and flux
A
+I
0
0
B
A.C.vectors.

Fig. 15.—M.M.F. from excitation as in Fig. 13 (2-phase).
(The signs refer to winding directions).

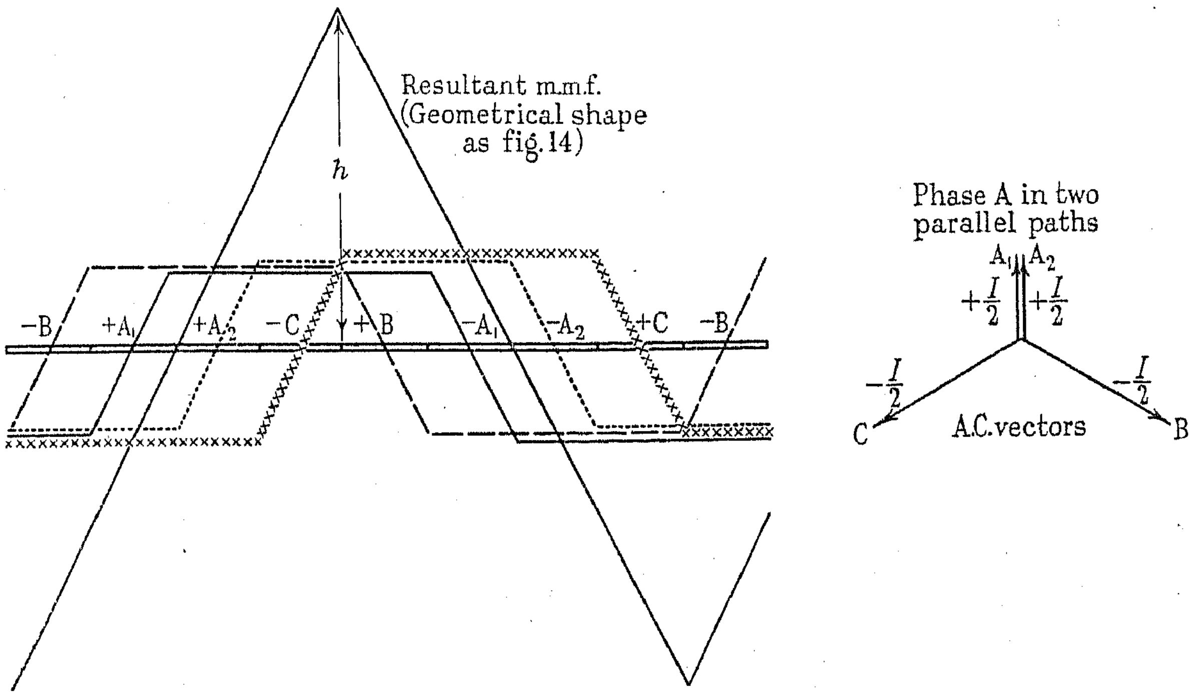

Resultant m.m.f. (Geometrical shape as fig.14)
h
−B
+A₁
+A₂
−C
+B
−A₁
−A₂
+C
−B
Phase A in two parallel paths
A₁ A₂
+I/2
+I/2
−I/2
−I/2
C
A.C.vectors
B

Fig. 16.—M.M.F. from excitation as method 8. One phase wound double.

M.M.F. due to phase A_1 ———— M.M.F. due to phase B – – –
M.M.F. due to phase A_2 .... M.M.F. due to phase C × × × ×
(The signs refer to winding directions).

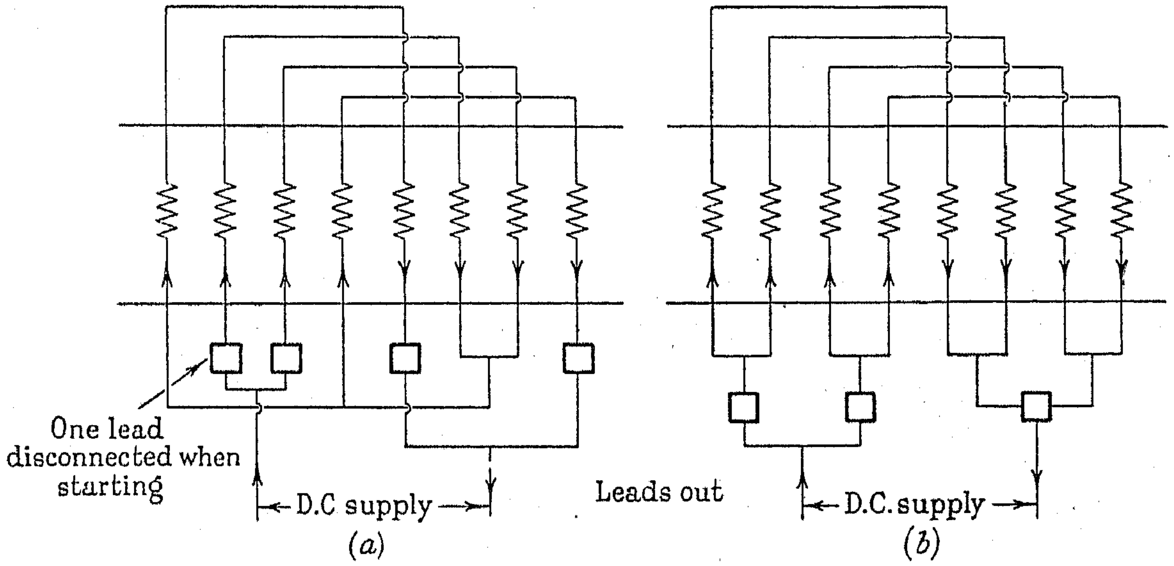


Fig. 17.—Schematic diagram of winding containing 4 phase bands per pole.

(a) Connected 3-phase star: one phase wound double.
(b) Connected 2-phase, parallel fed: 2 phase bands per pole in parallel.

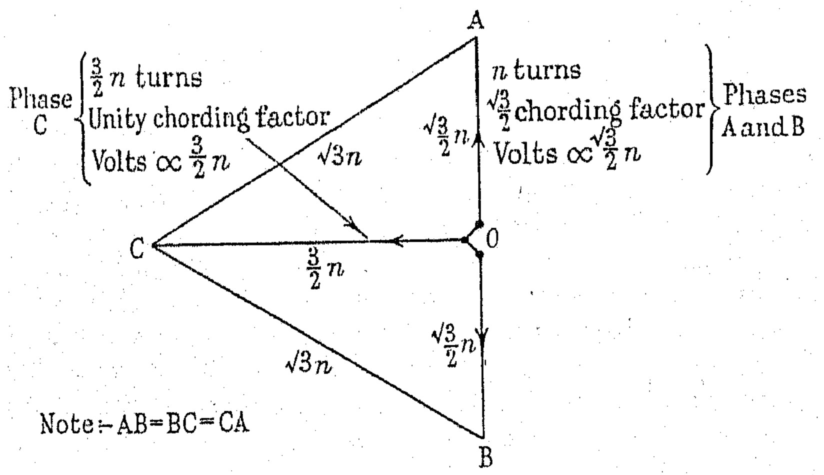


Fig. 18.—Three-phase unsymmetrical star, as Method 12 (Table 1).

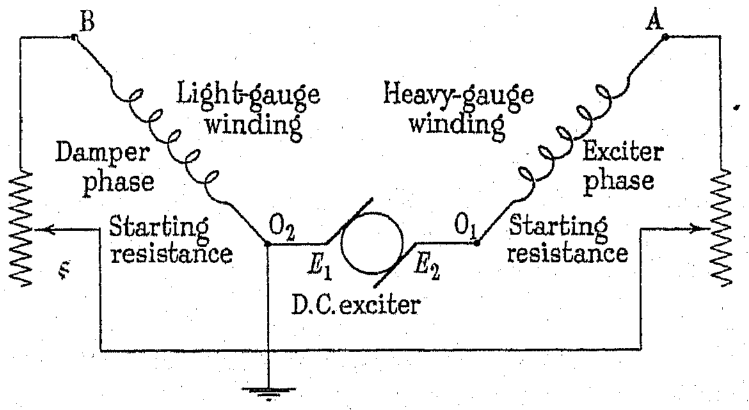


Fig. 19.—Two-phase rotor with single-phase excitation, and one phase as damper. Exciter earthed, and maximum voltage to earth is that of one phase.

synchronous action: theoretically, it would have to be connected to the mid-point of the exciter armature. Hence the damping and overload induction properties are relatively poor. If the V connection is made permanent and the phases excited in parallel, as Method 9, the damping and overload properties are improved. Finally, the third phase may be wound and used for starting in the usual way: for running it is short-circuited on itself, giving excellent damping and overload properties. This phase may be more lightly wound to save copper and to permit increased iron section at the centre of the poles. A French author[10] has recorded the use of iron wire for this phase, for cheapness and increased permeability of flux path.

An interesting winding is shown diagrammatically in Fig. 18.[11] It consists of 2 equal phases at 180° to each other with a winding pitch $\frac{2}{3}$ normal, and a third phase wound with $1\frac{1}{2}$ times as many turns of thinner " wire," in quadrature with both. When these are connected as an unsymmetrical star the secondary terminal voltages are balanced 3-phase. The winding is connected for excitation as Method 1, the third phase being paralleled with one of the first two. The greater resistance of the third phase, however, causes this system to be nearly equivalent electrically, when synchronized, to Method 2. It is claimed that Method 12 does, in fact, combine the advantages of Methods 1 and 2.

Table 2

TYPICAL RELATIVE PERFORMANCE FIGURES FOR VARIOUS TYPES OF MACHINE RATED AT 6 600 VOLTS, 3-PHASE, 50 C./S., 800 H.P., 176·5 R.P.M.

Type of machine	Starting torque, % full load	Starting current, % full load	Efficiency at full load, %	Synchronous pull-out torque, % full load	Excitation	
					amp.	kW
Standard salient-pole motor	50*	150*	93·5	220	125	15
Synchronous induction motor	100	150	91·5	150	600	21
Salient-pole synchronous induction motor..	100	200	93·5	200	220	14·5

* Auto-transformer starting: 50 % tap.

(c) Three-phase Delta

Methods 4, 15 and 16 (Table 1) show delta connections where one phase normally carries no current. It is always possible to reduce the copper section in this phase, and in Method 15 it may be completely omitted from half the winding without any deleterious effects. In Methods 4 and 16 it can also be omitted, but only if some sacrifice of starting, damping and overload properties can be tolerated.

(d) Two-phase Windings with Single-phase Excitation

All multi-phase excitation systems are inherently wasteful, since the vector sum of two or three sine waves displaced in space is less than their arithmetical sum. This fact has led to the use of single-phase excitation as Method 17 (Table 1) and Fig. 19. Method 7 (Table 1) is at a disadvantage since the heat is all generated in half the winding, but if the exciting phase is wound with relatively thick conductors and the damping phase with thinner conductors a much higher m.m.f./watts ratio will be obtained. If the thermal conductivity of the exciting phase insulation is reasonably good the heat will be much evened out. (See Appendix 2 for comparison of the efficiencies of single- and 3-phase excitation.) The numbers of turns in the two phases may be unequal, the starting resistances being suitably adjusted for optimum starting conditions.

Commonly the exciter is inserted between the two phases—though this means an extra secondary lead—because the maximum voltage to earth is thereby reduced to that of one phase. The term " auto-synchronous motor " has been applied[12] to this and other types of S.I.M. to imply that the machine is rather a synchronous motor with self-starting properties than an induction motor with synchronizing properties.

(e) Salient-pole Synchronous Induction Motor

In this type of S.I.M. the wheel has come almost full circle back to the synchronous machine.[13] A normal salient-pole machine of large pole arc is fitted, for starting and damping purposes, with a light 3-phase star winding, in the face of the poles, instead of a light squirrel-cage winding. When running synchronously the starting winding is short-circuited on itself, and normally carries no current. In principle this type of machine differs from all other S.I.M.'s in that the exciting and starting windings are entirely separate; and its advantages are higher synchronous pull-out torque, reduced exciter capacity and higher efficiency. Conversely, the starting current for a given starting torque is greater.

The load reactance is much reduced (see Section 6) by salient poles, and hence the increased " stiffness." Reduced exciter capacity is important both in itself and because it reduces the heat to be dissipated from the secondary. Typical figures[14] of comparative efficiencies for a synchronous machine, a salient-pole S.I.M. and a standard S.I.M. are given in Table 2, for a particular machine rating. It is interesting to compare the actual reduction in exciter capacity with the theoretical ideal given in Appendix 2. It may be necessary to short-circuit the exciting winding through a resistance when starting, to avoid a high voltage at its terminals. The number of secondary leads may be reduced by joining together one end of the exciting winding and one end of the starting winding.

It is common to use a larger air-gap with this type of S.I.M. than with other types. This to some extent offsets the greater magnetizing efficiency of the exciting winding, but it reduces the risk of magnetic pull-over and increases the stability.

(6) THE LOAD REACTANCE OF SYNCHRONOUS INDUCTION MOTORS WITH DIFFERENT METHODS OF EXCITATION

In the course of laboratory tests on S.I.M.'s employing several of the methods of excitation previously discussed, it occurred to the author that the method of excitation might have some effect on the load reactance and consequent " stiffness " of an S.I.M. Further, although it is well known that the terms " synchronous reactance " and " load reactance " each comprise effects due to both armature reaction and leakage reactance, no practical tests to confirm the relation between these quantities, in the particular case of an S.I.M. with barrel rotor, have been recorded. Hopkinson,[15] Rosenberg,[16] and Prescott,[17] have shown practically that the load reactance of a salient-pole synchronous machine is much less than the synchronous reactance, and have ascribed the difference to the differing " direct-on " and " cross " magnetizing coefficients. A short account of tests to determine the load and synchronous reactances with two representative methods of excitation (Methods 1 and 2, Table 1) at various saturations may thus be of interest.

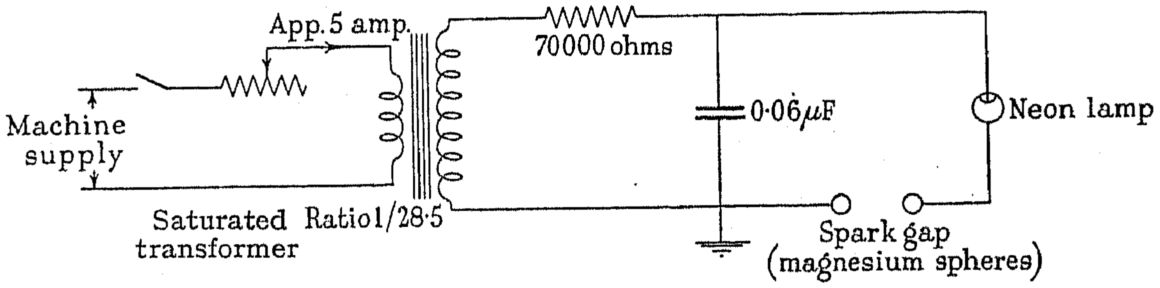


Fig. 20.—Stroboscope circuit.

Determination of Load Reactance

The method used was the stroboscopic one given by Prescott and Connon,[17] with slight simplifications in the stroboscope circuit itself, the circuit used being shown in Fig. 20. The object was to have the smallest possible number of components and high-potential points. Magnesium spheres (0·75 in. dia.) were used for the spark gap. Magnesium has a low " work function " and thus tends to spark consistently. The full-load angular shift of an S.I.M. is large, in this case 25 mechanical degrees, and the fixed scale must be suitably chosen. One scale division corresponded to 0·01075 mechanical radian. The machine rating was 200 volts, 3-phase, 50 c./s., 8 h.p., 1 500 r.p.m., 20 amp. full-load current at unity power factor; stator (primary) delta, rotor star; stator slots 48, rotor slots 36; air-gap 0·025 in.; stator conductors 816, rotor conductors 504. The load was applied to the S.I.M. by a d.c. machine coupled to it. The power factor was kept constant by suitable variation of the excitation.

Practical Results

A typical load-angle/load curve for one method of excitation is shown in Fig. 21, and a tabulated list of load reactances is given in Table 3. From the data above, it follows that

$$\text{Load reactance} = 6{\cdot}45 \times 10^{-5} V^2 \left[\frac{\text{Scale divisions}}{\text{Kilowatt}}\right]$$

where $V =$ line volts, and this formula was used to calculate all the load reactances in Table 3. The reduction in load angle with increased excitation, shown in Fig. 21, demonstrates elegantly the well-known increase in stability with increased excitation, hence the variable automatic system of excitation referred to in Section 3(*a*). The values of synchronous reactance, for various excitations, also shown in Table 3, were obtained by standard open-circuit and short-circuit tests.

Magnetic " Backlash "

It will be seen in Fig. 21 that there is a discontinuity in the load-angle curve passing through zero, which caused some difficulty in the determinations of the initial slopes XY and X'Y', Fig. 22. This " backlash " at zero load, which has not hitherto been noted, in the author's opinion arises from the fixing of the conductors in slots, making it possible to move the rotor through a limited distance without altering the flux distribution in the stator (see Fig. 23). It is likely to be more considerable in an S.I.M., with short air-gap and both stator and rotor slotted, than in a normal synchronous machine. The effect is of importance in determining the initial load-angle slope.

Notes on the Experimental Values of Reactance

The generating reactances were uniformly lower than the motoring reactances. When generating, the back e.m.f. exceeds the terminal voltage; when motoring, the back e.m.f. is less than the terminal voltage, by the amount of the resistance and leakage reactance-drops. Hence when generating, at a given voltage, the machine is slightly more saturated than when motoring and the reactance is less.

With both methods of excitation, the load reactance falls with increasing voltage and saturation. With Method 2, giving a flatter m.m.f. wave form, saturation arises more slowly and, as would be expected, the load reactance falls more slowly with rise of voltage than

Table 3

VALUES OF LOAD REACTANCE IN OHMS FOR VARIOUS VOLTAGES AND METHODS OF EXCITATION, BOTH MOTORING AND GENERATING, COMPARED WITH SYNCHRONOUS REACTANCE

Line voltage	Synchronous reactance with various methods of excitation			Load reactance 1 with excitation as Method 1 (Table 1)			Load reactance 1 as percentage of average synchronous reactance			Load reactance 2 with excitation as Method 2 (Table 1)			Load reactance 2 as percentage of average synchronous reactance			Load reactance 2 as percentage of load reactance 1		
	1	2	Avge.	Motoring	Generating	Avge.	Motoring	Generating	Avge.	Motoring	Generating	Avge.	Motoring	Generating	Avge.	Motoring	Generating	Avge.
							%	%	%				%	%	%	%	%	%
186	32·5	32·5	32·5	30·8	29·0	29·9	94·8	89·2	92·1	28·3	27·7	28·0	87·1	85·3	86·2	91·9	95·5	93·7
200	30·4	30·1	30·2	29·6	28·6	29·1	98·1	94·8	96·5	28·0	27·1	27·5	92·8	89·8	91·1	94·7	94·6	94·6
216	27·1	27·3	27·2	25·5	24·5	25·0	93·8	90·1	91·9	26·8	26·2	26·5	98·6	96·4	97·5	105	107	106

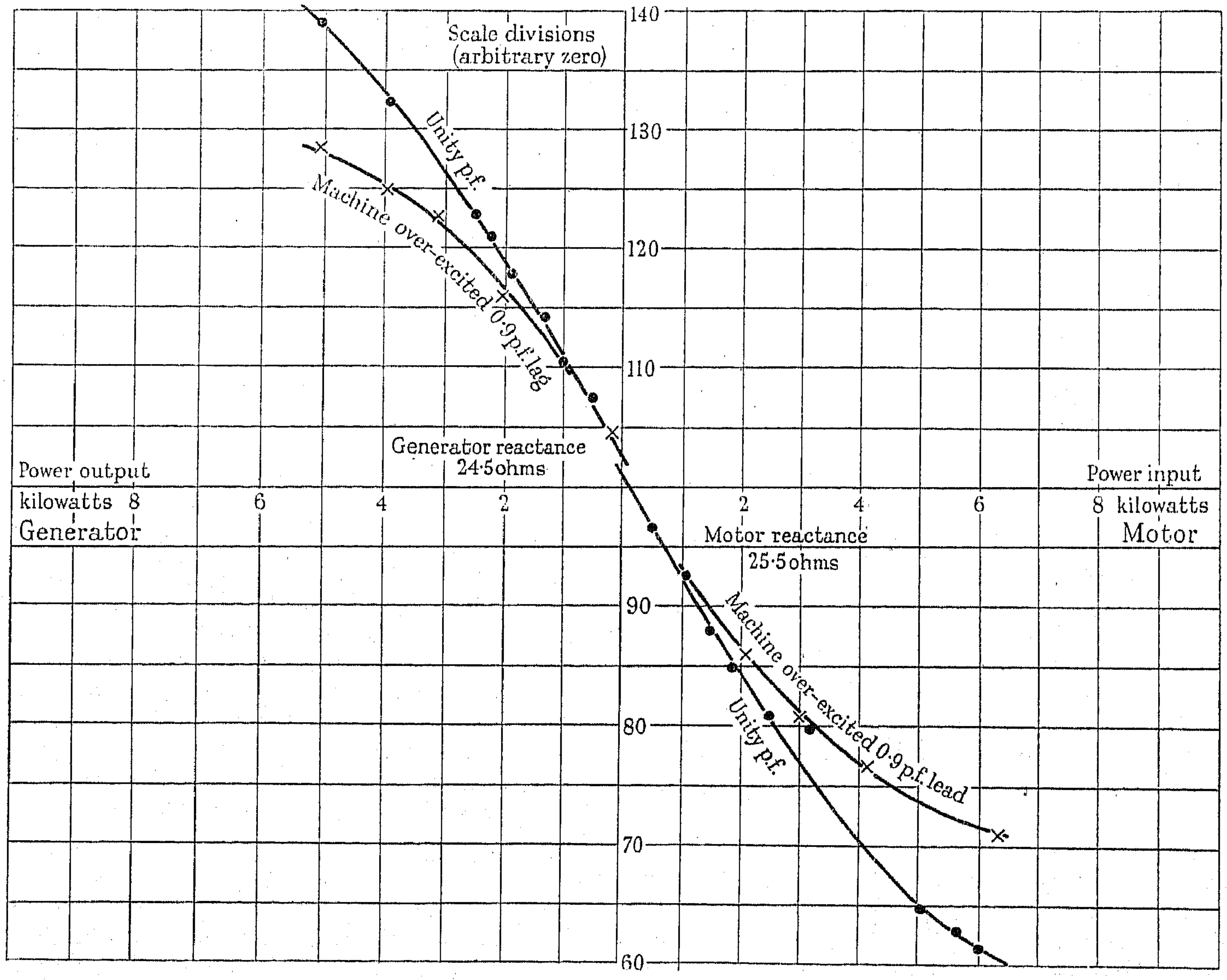


Fig. 21.—Load-angle/load curves for S.I.M.:—216 V, 3-phase, 50 c./s., 8 h.p., 1 500 r.p.m. Excitation as Method 1 (Table 1).
1 scale division = 0·01075 mechanical radian. Primary delta-connected.

with Method 1. Method 1 gives a higher reactance than Method 2 below saturation, but a lower reactance above saturation.

At any given degree of saturation the value of synchronous reactance is nearly independent of the method of excitation used, whereas the load reactance depends considerably on it. Synchronous reactance depends mainly on the fundamental armature and field m.m.f.'s and is only slightly influenced by harmonics[18] and the disposition of the secondary windings. Load reactance depends on a relatively small modification of the secondary field by the armature, and is thus sensitive to changes in secondary wave shape due to the disposition of the secondary windings. Hence the variations in the ratio of load to synchronous reactance, the ratio, however, being always less than unity; the average value being 0·925. It is clear, therefore, that with a barrel rotor the reactances approximate very closely.

Using the methods of Appendix 4 to obtain the ratio between d.c. exciting current and a.c. armature short-circuit current, the synchronous reactance can be separated theoretically into armature and leakage components. In these cases the average armature component is 0·93 of the corresponding synchronous reactance, and the average value of the ratio of the load reactance to the armature component of the synchronous reactance is unity. In these experiments the excitation was varied to keep the power factor unity. This slightly diminished the load angle for a given load and thus also the value of reactance. It would be expected that the load reactance with the power factor maintained at unity would be less than the synchronous reactance by an amount proportional to the ratio between leakage and synchronous reactances. For this reason the values 0·925 and 0·93, above, agree very closely. If the machine could have been operated with constant excitation the average ratio between load and synchronous reactances would almost certainly have been about unity, thus showing that the two reactances are essentially the same when the " cross " and " direct-on " magnetizing coefficients are the same. Finally, the value of load reactance varies considerably, though not radically, with different systems of excitation.

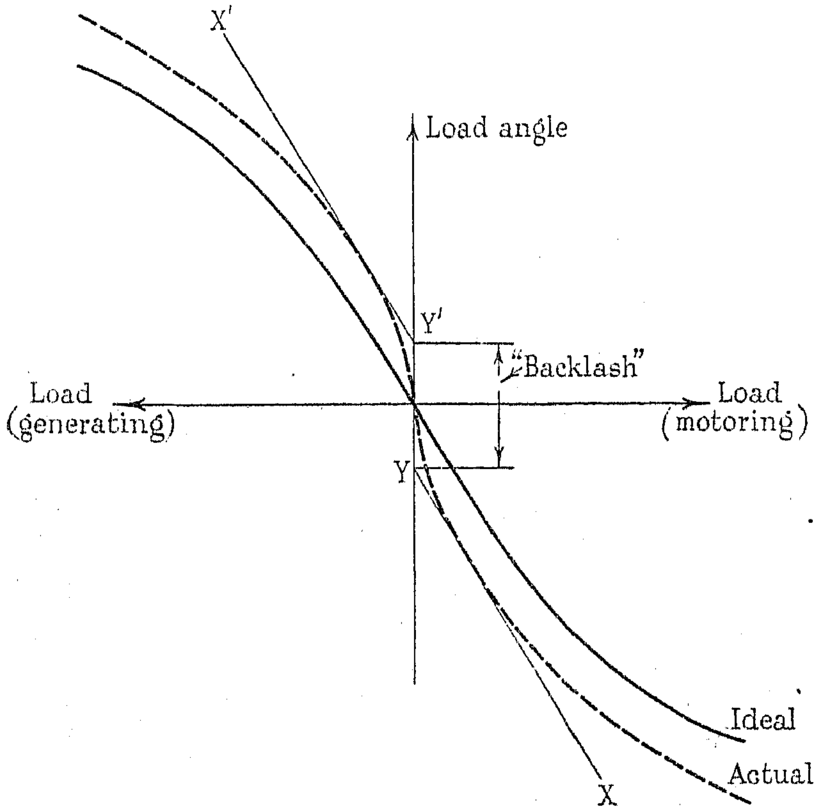


Fig. 22.—Magnetic " backlash " effect.

(7) HIGH-FREQUENCY ALTERNATING CURRENTS IN SECONDARY CIRCUITS

The author has known of trouble with the commutation of phase-advancers through high-frequency alternating currents in the secondary circuit of the motor to which they were applied. Since an S.I.M. exciter is virtually a phase-advancer of zero frequency the same effect might be expected with this, and the author has performed some tests to show the magnitude of this effect in a typical S.I.M. secondary circuit. A representative oscillogram, taken with a 2-element Duddell oscillograph, is reproduced in Fig. 24, showing an a.c. component of secondary current of about 10 %, the predominant frequencies being 6 and 24 times the primary supply frequency. In an S.I.M. there is no relative motion between the fundamental primary field and the secondary winding, and if the primary field were a pure sine wave there would be no induced a.c. voltage

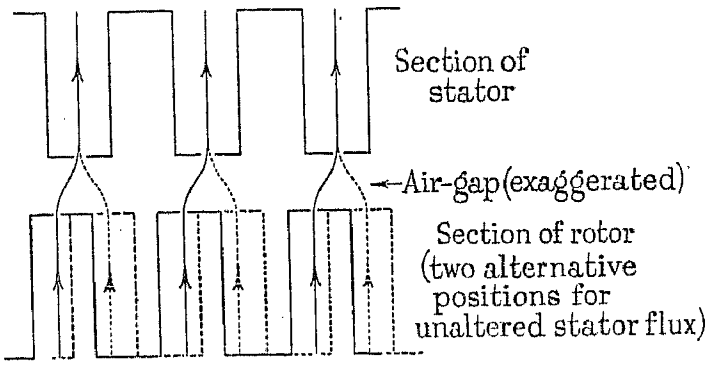

Section of stator
Air-gap (exaggerated)
Section of rotor (two alternative positions for unaltered stator flux)

Fig. 23.—Sketch illustrating magnetic " backlash."

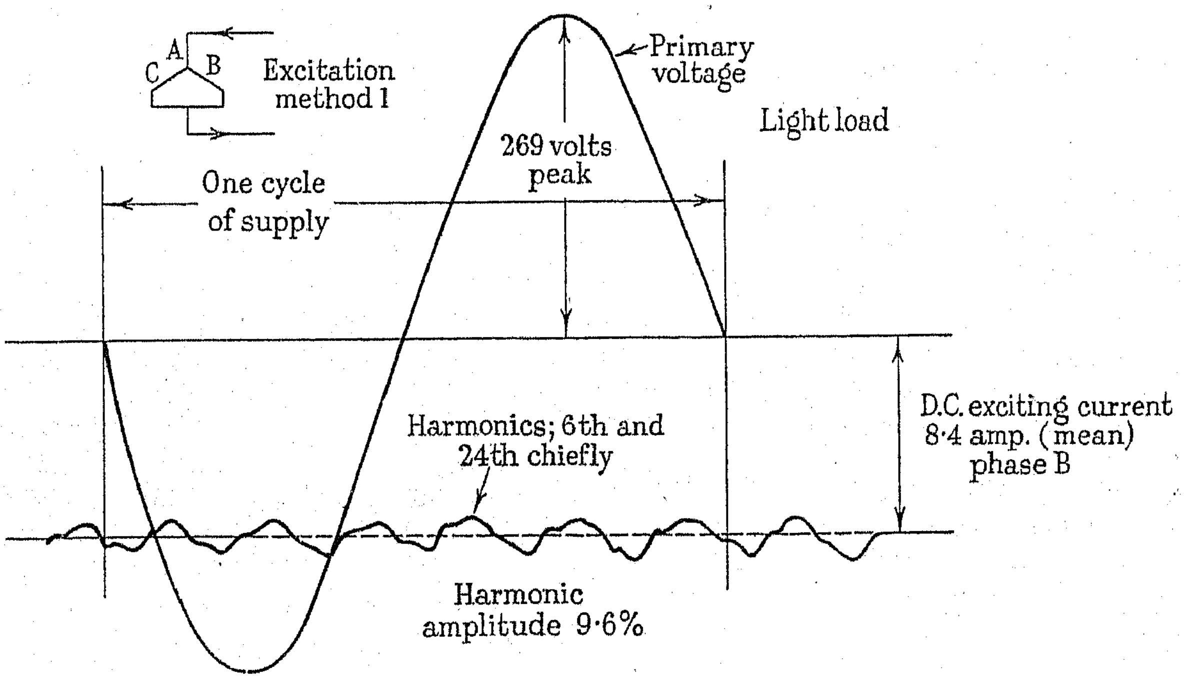


Fig. 24.—Sketch of typical oscillogram of exciting current of S.I.M.

in the secondary circuit. In fact, however, there are always harmonic fields of the $(2n \pm 1)$th order as well ($n = 3, 6, 9$, etc.). The positive sign gives fields rotating in the same sense as the fundamental, the negative sign in the opposite sense. Hence each pair of harmonic fields induces fields in the secondary of ($2n \times$ primary) frequency. The magnitude of the alternating currents depends on the secondary inductance, and a series choke would reduce them. If it were suspected that bad exciter commutation was due to this cause, the insertion of a suitable series choke would readily confirm or refute the suspicion. There were 48 slots on the primary of this 4-pole machine, giving slot harmonics of the 23rd and 25th orders. The observed a.c. secondary current thus corresponded to the leading harmonics, 5th and 7th, in the general field form, and to the slot harmonics, 23rd and 25th.

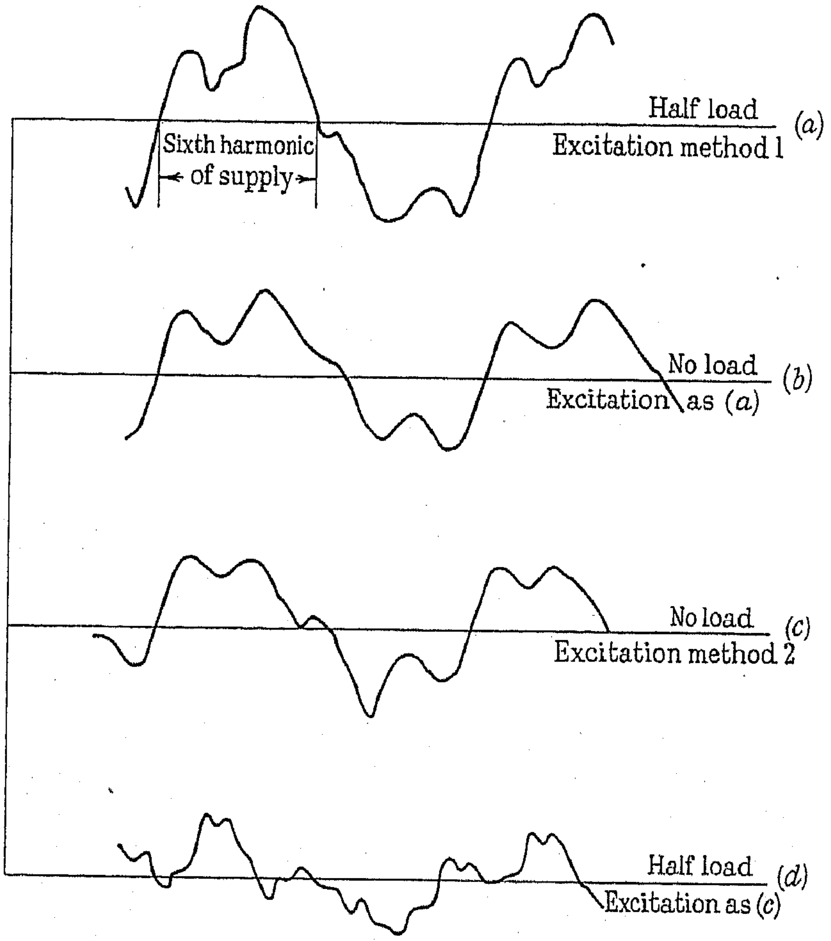


Fig. 25.—A.C. components of exciting current, all to arbitrary scales.

The oscillograms of exciter current were repeated, using a cathode-ray oscillograph and amplifier; this eliminated the d.c. component and magnified the a.c. component arbitrarily. Typical oscillograms for different loads and methods of excitation are shown in Fig. 25. A large family of harmonics of diminishing size were present and their form changed with variations in load, power factor and terminal voltage, all of which influence the air-gap flux distribution. The predominant harmonics throughout, however, were the 6th and 24th. The magnitude of the a.c. component of the secondary current of an S.I.M. is, in fact, some measure of the departure of the primary field form from a pure sine wave, though various devices (e.g. chording) can eliminate harmonic voltages when harmonic fluxes are present.

(8) ACKNOWLEDGMENTS

The author is indebted to The General Electric Co.; The English Electric Co.; Lawrence Scott & Electromotors, Ltd.; Crompton Parkinson, Ltd.; and Metropolitan-Vickers, Ltd., for information supplied towards the first part of the paper; to Messrs. G. Noble, B.Eng., Graduate, and W. Alexander, M.Sc., Associate Member, for assistance in the practical work; and to Prof. E. W. Marchant, D.Sc., Past-President, for his support of the work throughout.

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APPENDICES: SOME MATHEMATICAL RESULTS

(1) Fourier Analyses of M.M.F. Wave Forms

(a) Three-phase systems.

The m.m.f. wave form (Fig. 9) from excitation as Figs. 5 and 7 can be analysed into

$$\frac{9h}{\pi^2}\left(\sin\theta + \frac{1}{5^2}\sin 5\theta - \frac{1}{7^2}\sin 7\theta - \frac{1}{11^2}\sin 11\theta + \ldots\right)$$

where h = m.m.f. at centre of pole = $n_3 I_3$ ampere-turns,
n_3 = conductors per pole per phase,
and I_3 = max. phase current.

The m.m.f. wave form (Fig. 10) from excitation as Figs. 6 and 8 is, similarly,

$$\frac{6\sqrt{3}h}{\pi^2}\left(\sin\theta - \frac{1}{5^2}\sin 5\theta + \frac{1}{7^2}\sin 7\theta - \frac{1}{11^2}\sin 11\theta + \ldots\right)$$

where $h = \frac{1}{2}\sqrt{3}n_3 I_3$.

(The phase currents, for the same total watts loss as before, are $\frac{\sqrt{3}}{2}I_3$.) Hence the fundamental m.m.f. in all 3-phase cases is of amplitude $\frac{9}{\pi^2}n_3 I_3$, with a given total wattage of excitation, and there are also smaller-harmonic m.m.f.'s [see Sections 3(*c*) and 7].

(b) Two-phase systems.

The m.m.f. (Fig. 14) from excitation as Figs. 11 and 12 is

$$\frac{8h}{\pi^2}\left(\sin\theta - \frac{1}{3^2}\sin 3\theta + \frac{1}{5^2}\sin 5\theta - \ldots\right)$$

where $h = n_2 I_2/\sqrt{2}$,
n_2 = conductors per pole per phase, and
$I_2/\sqrt{2}$ = current per phase.

The m.m.f. (Fig. 15) from excitation as Fig. 13 is

$$\frac{16h}{\sqrt{2}\pi^2}\left(\sin\theta + \frac{1}{3^2}\sin 3\theta - \frac{1}{5^2}\sin 5\theta - \ldots\right)$$

where $h = n_2 I_2/2$, and I_2 = max. phase current.

Hence, in all 2-phase cases, the fundamental m.m.f. is $\frac{8}{\sqrt{2}\pi^2}n_2 I_2$, and the harmonics are of greater magnitude than with 3-phase excitation.

The m.m.f. wave form for Method 8 (Fig. 16) is the same shape as Fig. 14, but here $h = n_3 I_3$, where I_3 = external current and the fundamental m.m.f. is $\frac{8}{\pi^2}n_3 I_3$.

(2) Theoretical Comparison between 2-phase, 3-phase, and Single-phase Excitation

For a given secondary the total winding space is fixed, since the amount of iron to carry a given flux is also fixed. This winding space may contain either normal 2- or 3-phase windings or a single-phase concentrated winding. The latter will be assumed to occupy all the winding space, leaving none for a damping winding. This assumption is, of course, too favourable. On this basis the ratio of the watts necessary to produce a given m.m.f. in the three systems of excitation may be deduced. Suppose r, n, and a are the phase resistances, conductors per phase, and conductor cross-sections respectively, and that suffixes 2, 3, and 1 denote the three systems respectively. Suppose i, M, and W are the *external* excitation current, the fundamental m.m.f. component in ampere-turns, and the watts excitation respectively, with suffixes as before. Now it has been shown (Appendix 1) that for 2-phase parallel-fed excitation

$$M_2 = \frac{4}{\pi^2}i_2 n_2 \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

Similarly, for Method 1 of 3-phase excitation

$$M_3 = \frac{9}{\pi^2}i_3 n_3 \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Now if $M_2 = M_3$, $$\frac{i_2}{i_3} = \frac{9}{4}\left(\frac{n_3}{n_2}\right) \quad . \quad . \quad . \quad . \quad . \quad (3)$$

But $$\frac{W_2}{W_3} = \frac{2\left(\frac{i_2}{2}\right)^2 r_2}{\frac{3}{2}(i_3)^2 r_3} = \frac{1}{3}\left(\frac{i_2}{i_3}\right)^2\frac{r_2}{r_3} \quad . \quad . \quad . \quad (4)$$

Now $$\frac{r_2}{r_3} = \left(\frac{n_2}{n_3} \times \frac{a_3}{a_2}\right) \text{(by Ohm's law)} \quad . \quad . \quad (5)$$

and, since the winding space is fixed,

$$2a_2 n_2 = 3a_3 n_3 \quad . \quad . \quad . \quad . \quad . \quad (6)$$

Eliminating between (3), (4), (5) and (6) we have

$$\frac{W_2}{W_3} = \frac{9}{8}$$

that is, the same m.m.f. necessitates 12½ % more watts in a 2-phase system.

The fundamental component of a single-phase concentrated winding is

$$M_1 = \frac{4}{\pi}i_1\frac{n_1}{2} = \frac{2}{\pi}i_1 n_1 \quad . \quad . \quad . \quad . \quad . \quad (7)$$

As before, $$M_3 = \frac{9}{\pi^2}i_3 n_3 \quad . \quad . \quad . \quad . \quad . \quad (8)$$

If $M_1 = M_3$, $$\frac{i_1}{i_3} = \frac{9}{2\pi}\left(\frac{n_3}{n_1}\right) \quad . \quad . \quad . \quad . \quad . \quad (9)$$

Now $$\frac{W_1}{W_3} = \frac{i_1^2 r_1}{\frac{3}{2}i_3^2 r_3} = \frac{2}{3}\left(\frac{i_2}{i_3}\right)^2\frac{r_1}{r_3} \quad . \quad . \quad . \quad (10)$$

also $$\frac{r_1}{r_3} = \frac{n_1}{n_3} \times \frac{a_3}{a_1} \text{(by Ohm's law)} \quad . \quad . \quad . \quad (11)$$

and, since the winding space is fixed,

$$a_1 n_1 = 3a_3 n_3 \quad . \quad . \quad . \quad . \quad . \quad (12)$$

Eliminating, as before,

$$\frac{W_1}{W_3} = \frac{4 \cdot 5}{\pi^2} = 0 \cdot 456$$

That is, the same m.m.f. ideally needs less than half the wattage with single-phase excitation. Even after correction for some spreading of the concentrated winding, and for the space occupied by the damping winding, the reduction in wattage has been found to be about 30 % compared with 3-phase excitation (see Table 2).

Since, for a given winding, the m.m.f. is proportional to the square root of the watts, the ratios of m.m.f. produced for a fixed wattage can readily be deduced from the above.

(3) Starting and Overload Properties with Single-phase Secondaries

If one lead to a 3-phase winding, star or delta, is broken there is left, effectively, a single-phase winding between the two remaining leads. The properties of induction motors with single-phase secondaries are discussed by Arnold,[1] and it need only be recalled that at half synchronous speed there is a dip in their speed/torque curve which may decrease the torque below zero. The dip is reduced by increased secondary resistance, and Arnold shows that the torque can always be made positive over the whole speed range. Mauduit[19] shows a family of speed/torque curves which never become positive at half speed, but he is, in the author's opinion, mistaken. It may be recorded that the author, confronted with this contradiction, conducted some tests which bore out Arnold's theory.

If the turns disposition of the 3 windings of an induction motor is given by

$$T_1 = T_m \sin p\theta, \quad T_2 = T_m \sin\left(p\theta - \frac{2\pi}{3}\right),$$

$$T_3 = T_m \sin\left(p\theta - \frac{4\pi}{3}\right)$$

and the 3-phase currents are

$$I_1 = I_m \sin \omega t, \quad I_2 = I_m \sin\left(\omega t - \frac{2\pi}{3}\right),$$

$$I_3 = I_m \sin\left(\omega t - \frac{4\pi}{3}\right)$$

then the normal induction field is

$$I_1T_1 + I_2T_2 + I_3T_3 = \tfrac{3}{2}I_mT_m \cos(p\theta - \omega t) \quad . \quad (13)$$

If one phase is omitted but the star point brought out so that the other two phase currents preserve their proper vector relationship, then the field due to the two phases is

$$I_2T_2 + I_3T_3 = I_mT_m \cos(p\theta - \omega t) + \tfrac{1}{2}I_mT_m \cos(p\theta + \omega t) \quad . \quad . \quad . \quad (14)$$

If, however, we take 2 phases (say T_2 and T_3) and feed one phase current (say I_1) into it the field is

$$I_1(T_2 - T_3) = \frac{\sqrt{3}}{2}I_mT_m \sin(p\theta - \omega t) - \frac{\sqrt{3}}{2}I_mT_m \sin(p\theta + \omega t) \quad . \quad (15)$$

If therefore only two phases of a 3-phase winding are used but the neutral (OD) is connected as shown in Fig. 26, the forward rotating field is two-thirds of the normal induction field and the backward one-third of this, whereas if the neutral is omitted both fields are equal and each only $1/\sqrt{3}$ of the normal field. In the latter case the half-speed crawling tendencies will obviously be the worse.

The frequency of the currents induced in the primary by the backward rotating field is $(1 - 2s) \times$ supply frequency, where s is the slip. "Beats" will therefore be produced in the primary circuit near semi-synchronism, where $(1 - 2s)$ is nearly zero, and near synchronism, where this frequency is nearly equal to that of the supply and therefore "beats" with it. Method 2 of excitation, for example, gives beats in the primary circuit just before synchronizing.

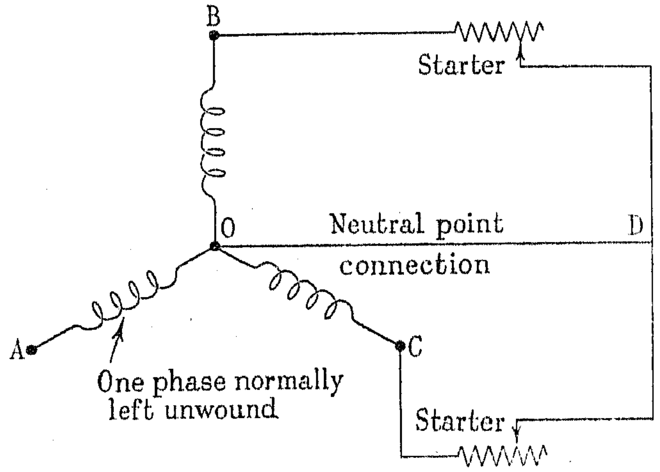

Fig. 26.—Basic connections for "3-phase" star rotor, with only 2 phases wound.

(4) A Note on the Computation of Exciting Currents in Synchronous Induction Motors

The excitation is computed by resolving vectorially the magnetizing and the load balancing currents (the latter may include wattful and wattless components) as for synchronous machines. The special problem with S.I.M.'s is to deduce the magnitude of these quantities before resolving them.

Suppose I_{AC} is the r.m.s. primary a.c. magnetizing current per phase, using the machine as an induction motor: this is computed by the normal methods of induction-motor design. If w is the winding ratio, wI_{AC} is the equivalent secondary current. Hence the direct current for no-load excitation must equal the instantaneous value of alternating current at the vector position which it has been decided to stabilize.

Hence, for example, with Method 1 of excitation

$$I_{DC} = \sqrt{2}wI_{AC}$$

or, with Method 2,

$$I_{DC} = \frac{\sqrt{3}}{2} \times \sqrt{2}wI_{AC} = \sqrt{\frac{3}{2}}wI_{AC}$$

Similar considerations hold for computating the excitation to balance the a.c. load.

THE EFFECTIVE INDUCTANCE AND RESISTANCE OF SCREENED COILS*

By A. G. BOGLE.†

(*Paper first received* 28*th November*, 1939, *and in revised form* 10*th April*, 1940.)

SUMMARY

In this paper an effort has been made to determine simple and workable formulae for the changes produced in the characteristics of an air-core coil by placing it in a screening container. The formulae, which have been derived empirically, are based upon the simplified case of a solenoidal coil of infinite length, placed coaxially in an infinitely long cylindrical screen. Another simplification, namely that of regarding the coil-and-screen system as a flat band of wires placed parallel to a conducting plane, is also mentioned, and from these two simple cases it has been possible to proceed, by application of the results of measurement, to formulae for inductance and resistance change so simple that they almost amount to workshop rules. These formulae are shown to cover all practical cases of finite coils and coaxial screens to an accuracy within 2 %.

The effects of proximity of ends, small deformations and displacements, and temperature changes, are also examined and estimated.

The shape of the curve of eddy-current distribution in the screen is examined, and it is found that the shape of curve derived from search-coil measurements is very similar to that derived from calculation on the basis of regarding the coil as a flat system.

LIST OF SYMBOLS

A = vector potential.
A_2, A_4, A'_2, etc. = constants depending on shape of coil and screen.
a = radius of screen.
B = constant in inductance formula.
b = radius of coil.
C = capacitance.
c = a constant, and also = radius of search coil.
d = thickness of screen material.
e = exponential.
F = power factor, and also = $R/(\omega L)$.
f = frequency.
G = a constant.
$g = a - b$.
H = magnetic field inside screen.
h = magnetic field inside coil.
I = current in screen.
i = current in coil.
L_1 = unscreened inductance of the coil.
L_2 = screened inductance of the coil.
l = length of coil.
l_t = length of screen tube.

LIST OF SYMBOLS—*continued.*

M = mutual inductance.
$\frac{1}{m} = \sqrt{\left(\frac{\rho}{2\pi\omega}\right)}$
P = power loss in screen.
$N^2 = \frac{1}{\sigma_0^2 l}\int_{-\infty}^{+\infty} \sigma^2 dx$
n = number of terms in series.
R' = increment of coil resistance due to screen currents.
r = radius of wire.
U = number of turns per unit length of coil.
$x = \frac{\rho}{2\pi a d\omega}$
x_1, x_2 = distances.
y = axial movement of coil, in cm.
Z = impedance.
$z = \sqrt{\left(\frac{8\pi f r^2}{\rho}\right)}$
α = temperature coefficient of linear expansion of copper.
β = temperature coefficient of resistivity of copper.
δ = percentage decrease of diameter of coil.
ϵ = eccentricity of coil in screen.
λ = wavelength.
ρ = resistivity.
σ_0 = maximum line-current-density in screen.
τ = temperature.
Φ = magnetic flux.
$\omega = 2\pi f$.

PART 1

THEORETICAL INVESTIGATION

(1) Introduction

It is common practice to place an inductance coil inside a closed metallic screen in order to prevent mutual electromagnetic action between it and neighbouring apparatus, and it is well known that the inductance of the coil is decreased by the screen and its resistance is increased. It is a problem in electromagnetism which invites a purely mathematical treatment. But it is obvious from the outset that such treatment must be very involved and would necessarily lead to formulae too cumbersome to be of much practical use. Since inductances can be measured to any degree of accuracy, a simple and universal formula which will suffice to predict the inductance of a screened coil to an accuracy of, say, 2 or 3 per cent, is likely to be of more practical use than a very complicated formula which would be valid to a higher order of accuracy. The work described in this paper was undertaken with the intention of finding universal empirical formulae of great simplicity which would suffice to predict the effect of a screen. Accordingly a classical approach by mathematics was ruled out and instead the basic principles of electromagnetism have been used as a pointer to suggest the general form of an empirical expression. Recognizing that the energy of a magnetic field (in other words, inductance) has to satisfy a minimum theorem and is therefore insensitive to small changes of distribution, there seemed reason to hope that a very simple formula could be found. Or, putting it in another way, if an exact and general mathematical solution were obtained it would be cumbered by terms which would in fact be very insensitive to changes in the shape of the coil and the screen.

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† University of Oxford.

Before going further, it is perhaps helpful to illustrate the problem by a very simple example. Suppose a very long solenoid of radius b, wound with U turns per unit length, is placed coaxially inside a very long tube of radius a: a cross-section of the arrangement is shown diagrammatically in Fig. 1. A circumferential current will now be induced in the tube by the alternating flux inside the solenoid produced by the simple harmonic current i in its winding. By Lenz's law, the current induced in the tube will tend to have that value which makes the net change of flux through the tube zero at every instant. Now a current i in the solenoid will produce a magnetic field $h = 4\pi iU$ inside it, and hence a flux $\Phi = \pi b^2 h = 4\pi^2 iUb^2$ through the tube. Similarly, if a circumferential current flows in the tube, of magnitude I per unit axial length, it will produce a magnetic field $H = 4\pi I$ inside the tube and the total flux due to it will be $\pi a^2 H = 4\pi^2 a^2 I$. If the rate of change of flux inside the tube is to be zero, then I must have such a value that the flux due to it is equal and opposite to the flux through the tube due to the current i in the solenoid. Hence

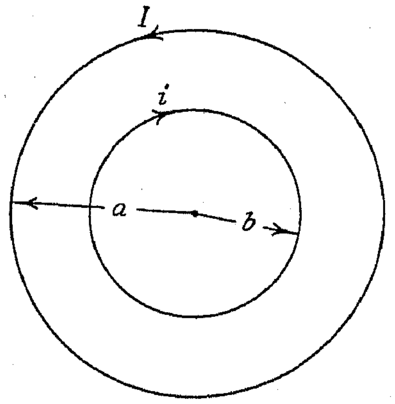

Fig. 1.—Coil of radius b inside tube of radius a.

$$4\pi^2 b^2 iU = 4\pi^2 a^2 I$$

$$\therefore \quad I = iU\frac{b^2}{a^2} \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

When the screen is removed the solenoid has an inductance $L_1 = 4\pi^2 b^2 U^2$ per unit length, but inside the tube its effective inductance is decreased by the currents induced in the tube, and has the value

$$\begin{aligned} L_2 &= \pi b^2 U(h - H) \\ &= 4\pi^2 b^2 U^2\left(1 - \frac{b^2}{a^2}\right), \text{ from (1)} \end{aligned}$$

$$\therefore \quad \frac{L_1 - L_2}{L_1} = \frac{b^2}{a^2} \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

It follows from (2) that the fractional decrease of inductance is equal to the ratio of the cross-sectional area of the solenoid to that of the tube. It should be noted that this result is perfectly general and does not depend (at any rate, to the first order) on the shape of the cross-section of the solenoid or the tube, provided only that each may be regarded as very long.

It is important to realize that, according to (1), the current induced in the tube is independent of the specific resistance, and accordingly that the efficacy of a screen does not depend on the material of which it is made. Since the induced current does not depend on resistance, it follows that it will cause an energy loss which is proportional to the resistance: in other words, the use of copper rather than tinned iron is important only in limiting as much as possible the increase of effective resistance of the screened coil, and not in improving the efficacy of the screen as a screen.

(2) The Frequency and Resistance Effect

Clearly, equation (1) cannot be precise as it stands, for the induced current cannot really be independent of resistance, and indeed equation (1) was formulated for an extreme case. It will now be shown that this limit is sensibly attained in all cases of practical interest. Let the tube have a thickness d of material of specific resistance ρ: let the current in the solenoid be $i_m \sin \omega t$ and that in the tube $I_m(\sin \omega t + G \cos \omega t)$. Then the net flux through the tube is

$$\Phi = 4\pi^2\left[b^2 U i_m \sin \omega t + a^2 I_m (\sin \omega t + G \cos \omega t)\right]$$

also
$$\frac{d\Phi}{dt} = \frac{2\pi a\rho}{d} I_m(\sin \omega t + G \cos \omega t)$$

Solution of these equations yields the values of I_m and G, but it is simpler to write down the solution in terms of a voltage $4\pi^2 b^2 \omega iU$ inducing a current in a circuit having an inductance $L = 4\pi^2 a^2$ and a resistance $R = 2\pi a\rho/d$; accordingly

$$\begin{aligned} I &= \frac{4\pi^2 b^2 \omega iU}{\sqrt{\left(\dfrac{4\pi^2 a^2 \rho^2}{d^2} + 16\pi^4 a^4 \omega^2\right)}} \\ &= iU\frac{b^2}{a^2} \times \frac{1}{\sqrt{\left(1 + \dfrac{\rho^2}{4\pi^2 a^2 d^2 \omega^2}\right)}} \quad . \quad . \quad (3) \\ &\equiv iU\frac{b^2}{a^2} \times \frac{1}{\sqrt{(1 + x^2)}} \quad . \quad . \quad . \quad . \quad (3a) \end{aligned}$$

Comparing equations (1) and (3), it may be seen that (1) is the limiting form of (3) when the second term under the radical becomes small. Suppose, for example, a copper tube (ρ = 1 680 c.g.s. units), in which a = 5 cm. and d = 2 mm.: then x is less than 1/25 if f is greater than 1 kc./s. Hence for such a tube equation (1) is correct to an accuracy closer than 0·1 % for all frequencies greater than 1 kc./s. This is not, however, quite the degree of accuracy of equation (2): the correct form of this equation follows at once from the well-known expression for the input impedance of a transformer having circuit parameters L_1, R_1, M, etc. On inserting the appropriate values of M, etc., it thus follows that

$$Z = R_1 + \left(\frac{2\pi a\rho}{d}\frac{b^4}{a^4}U^2 \times \frac{1}{1+x^2}\right) + j\omega L_1\left(1 - \frac{b^2}{a^2} \times \frac{1}{1+x^2}\right) \quad . \quad . \quad (4)$$

Hence $$\frac{L_1 - L_2}{L_1} = \frac{b^2}{a^2} \times \frac{1}{1+x^2} \quad . \quad . \quad . \quad . \quad (5)$$

Equations (5) and (2) differ only by the term in x^2, and it has been seen that for all practical cases x is likely to be less than 1/25; and hence it follows that the screen tube produces a decrease of inductance which is independent of frequency to an accuracy much closer than 0·1 %.

Equations (3) to (5), however, assume that the induced current is distributed uniformly over the wall thickness d, whereas with rising frequency it will in fact tend to concentrate round the inner circumference, with a consequent increase of effective resistance, and thereby, a change in the value of x. The appropriate value of x at any frequency could no doubt be derived in terms of Bessel functions, but to do so would be of little value. For above a certain frequency, to be determined, the graph of the distribution of current across the wall thickness d will differ insensibly from a simple exponential curve, and then it is well known that d in equations (3), etc., must be replaced by $\sqrt{\rho/(2\pi\omega)} \equiv 1/m$. Accordingly,

$$x' = \frac{\rho m}{2\pi a\omega} = dmx \quad . \quad . \quad . \quad . \quad (6)$$

According to the assumption of an exponential distribution, the ratio of current densities at the outside and inside surfaces would be e^{-md}. If md is greater than 4 this ratio is less than 1/50, and accordingly is negligible: then it will be valid to replace d by $1/m$, a substitution strictly permissible only if d is infinite. For copper sheet 2 mm. thick, $md > 4$ if $f > 20$ kc./s.: if $d = 0{\cdot}5$ mm., $md > 4$ provided $f > 300$ kc./s. Suppose, for example, that $a = 5$ cm., $d = 0{\cdot}5$ mm. and $f = 300$ kc./s.; then $x = 5{\cdot}7/10^4$ and $x' = 24{\cdot}0/10^4$. Hence $(1 + x'^2)$ differs from unity by about 6 parts in 10^6. Therefore, even when skin effect in the screen tube is allowed for, it still holds that the change of inductance is independent of frequency in all cases of practical interest. Though this has been deduced for a long solenoid inside a long tube, the same general result must hold for all finite coils, and this proposition will now be taken as established.*

(3) Short Coil Fitting rather Closely in a Long Tube

If in Fig. 1 the clearance $a - b \equiv g$ becomes small compared with a, the effect of the curvature will tend to be unimportant and the problem will tend to that of a plane band of wires at a distance g from an infinite conducting plane, as shown in Fig. 2. The inductance of this belt in the presence of the plane is equal to half the inductance of a circuit formed by the band and its image. Provided that $l/g >> 1$, the inductance per unit length of the band distant g from the screen will thus be $4\pi g U^2 l$, and thence $L_2 \simeq 4\pi g U^2 l \times 2\pi b$.

It is well known that L_1 can be expressed by the empirical relation (to an accuracy closer than 2 % if $l/b > 0{\cdot}4$):

$$L_1 = 4\pi^2 b^2 U^2 l \times \frac{1}{1 + 0{\cdot}868\frac{b}{l}} \quad . \quad . \quad . \quad (7)$$

Hence $$\frac{L_1 - L_2}{L_1} = 1 - \frac{2g}{b}\left(1 + 0{\cdot}868\frac{b}{l}\right) \quad . \quad . \quad (8)$$

Written in this form, (2) becomes

$$\frac{L_1 - L_2}{L_1} = \left(1 - \frac{g}{a}\right)^2 = 1 - \frac{2g}{a} + \frac{g^2}{a^2} \quad . \quad . \quad (9)$$

If $b/l << 1$, equations (8) and (9) become sensibly the same when $a \simeq b$. Hence it seems likely that equation (8) will form a rough guide for estimating the change of inductance of almost any coil inside a very long tube: it must be appreciably wrong when b/a is small, but then the change of inductance will be small, and hence the failure will not be important.

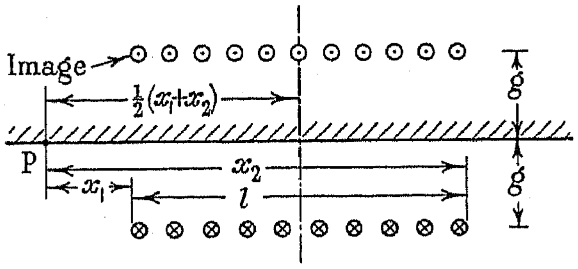

Fig. 2.—Flat band of width l, distant g from flat conducting plate.

Equation (8) may be rewritten

$$\frac{\Delta L}{L} = \frac{\left[1 - \frac{2g}{b}\left(1 + 0{\cdot}87\frac{b}{l}\right)\right]}{\left(1 - \frac{g}{a}\right)^2} \times \frac{b^2}{a^2}$$

$$\simeq \left(1 - \frac{2g}{a}\right)\left(1 - 1{\cdot}74\frac{g}{l}\right) \times \frac{b^2}{a^2}$$

$$\simeq \frac{l/g}{\frac{l}{g} + 1{\cdot}74} \times \frac{b^2}{a^2}, \text{ when } l << a \quad . \quad (10)$$

PART 2

APPLICATION OF THE THEORY TO PRACTICAL CASES

(1) Method of Measurement, and Details of Coils

The unscreened coil and a variable condenser formed the oscillatory circuit of a simple dynatron generator, and the frequency was adjusted to coincide with that of a separate generator (usually a convenient broadcasting station): the coil was then inserted in the screen and the capacitance increased until the frequency was restored to its original value.

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* In taking $L = 4\pi a^2$, the inductance due to flux within the thickness d has been ignored; this flux will tend to disappear with increasing frequency. Hence it follows that the true value of the parameter x is slightly less than that given by its definition, whereas x' will tend to be correct according to the assumed current distribution. Accordingly equations (5) and (6) have the merit of tending, if anything, to over-estimate the frequency effect.

A tube of commercial copper (specific resistance 4·78 microhm-cm., 5·08 cm. inside radius, 2·5 mm. thick) was used as the screen. Five formers (ebonite or glass) having radii ranging between 2·11 cm. and 4·58 cm. were wound with wire (No. 24 or No. 26 S.W.G. d.s.c.) for lengths ranging between 2·3 and 27 cm., providing a very wide range of shapes and sizes. Each of these coils was surrounded by various lengths of tube. Thus the effect could be studied of varying all the parameters: the effects of end plates and of eccentricity were also investigated.

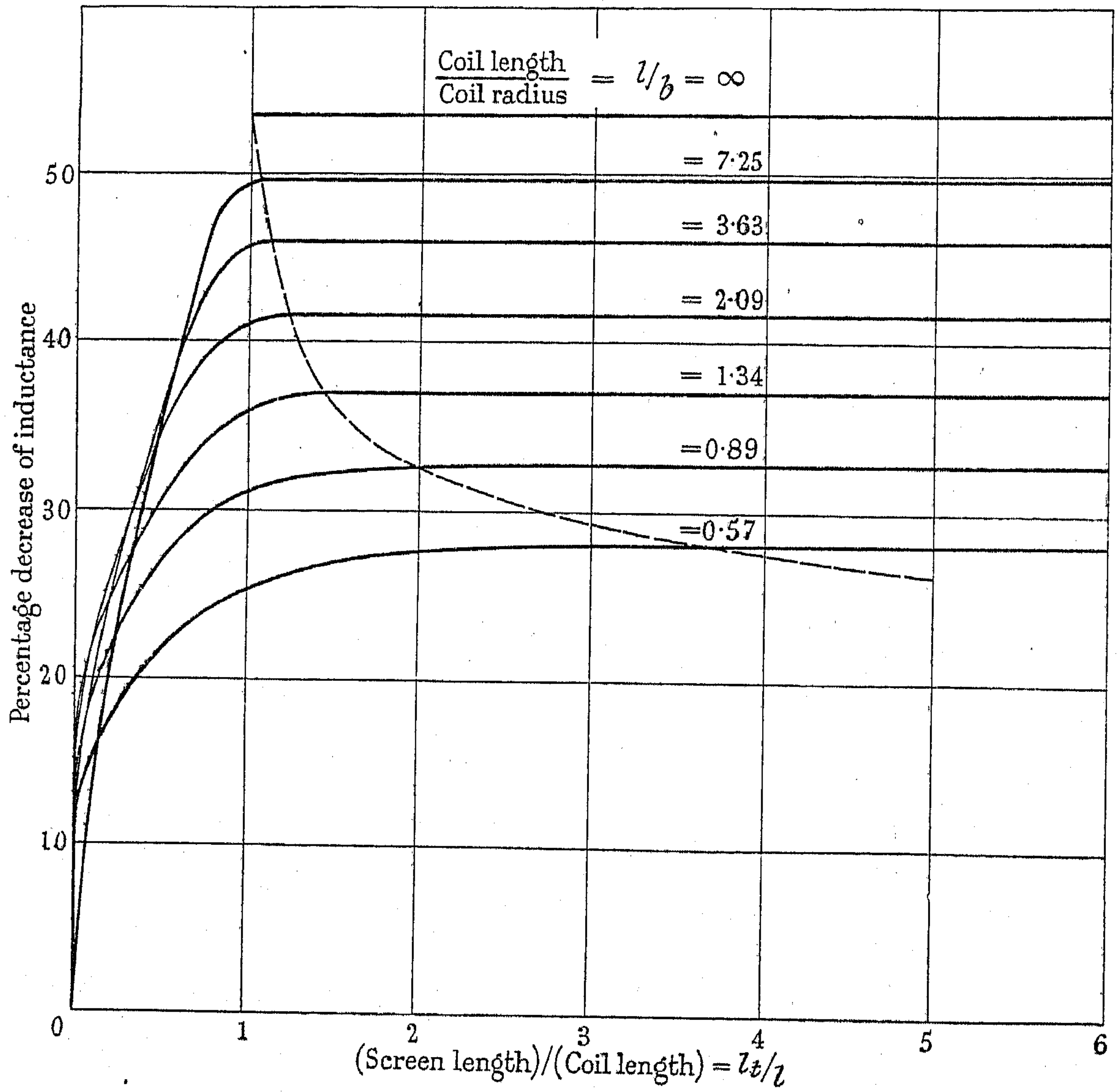

Fig. 3.—Effect of length of screen tube: coils of constant size ($b/a = 0\cdot73$) and various shapes.

(2) Effect of Varying Lengths of Screen and Coil

Fig. 3* relates to measurements on coils of various lengths, all having a radius of 3·71 cm. The fractional decrease of inductance is plotted as a function of the ratio $\frac{\text{Tube length}}{\text{Coil length}}$ for six coils in which the ratio $\frac{\text{Coil length}}{\text{Coil radius}} \equiv \frac{l}{b}$ ranged from 0·57 to 7·25. For each shape of coil there is a certain length of tube which is sensibly equivalent to an infinite length: the longer the coil the more nearly does this limiting length of tube approach the length of the coil it surrounds. It may be seen that when $l/b = 7\cdot25$, the limiting value of $\Delta L/L$ is 49·6 %. [If l/b had been infinite, then according to (2) the limiting value of $\Delta L/L$ would have been $b^2/a^2 = (3\cdot71/5\cdot08)^2 = 53$ %, and thus the idealized treatment of Part 1 is already substantially fulfilled.] It may be seen that for this value of l/b the tube need not be appreciably longer than the coil.

Fig. 4 shows results corresponding to those of Fig. 3 but for the coil of smallest radius, namely 2·11 cm. ($b/a = 0\cdot42$), and is of the same general character as Fig. 3: it is unnecessary to reproduce the corresponding curves for the coils of other radii. The dotted curve in Figs. 3 and 4 has been drawn through that point on each curve for which $\Delta L/L$ may be considered (perhaps rather arbitrarily) to have reached its limiting value: thus, for example, in Fig. 3 $\Delta L/L$ has been deemed to have reached its final value for a coil in which $l/b = 1\cdot34$ when the length of the tube l_t is $1\cdot45l$. The dotted curves typified in Figs. 3 and 4 have been used to produce Fig. 5, which shows l_t/l plotted as a function of l/b: it may be seen that l_t/l depends much more on the shape (l/b) of the coil than on its size (b/a).

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* In Figs. 3, 4, 6, 12 and 14 the observation points, if plotted, would coincide with the curves drawn; for this reason it has been considered permissible to avoid complexity and confusion by omitting them.

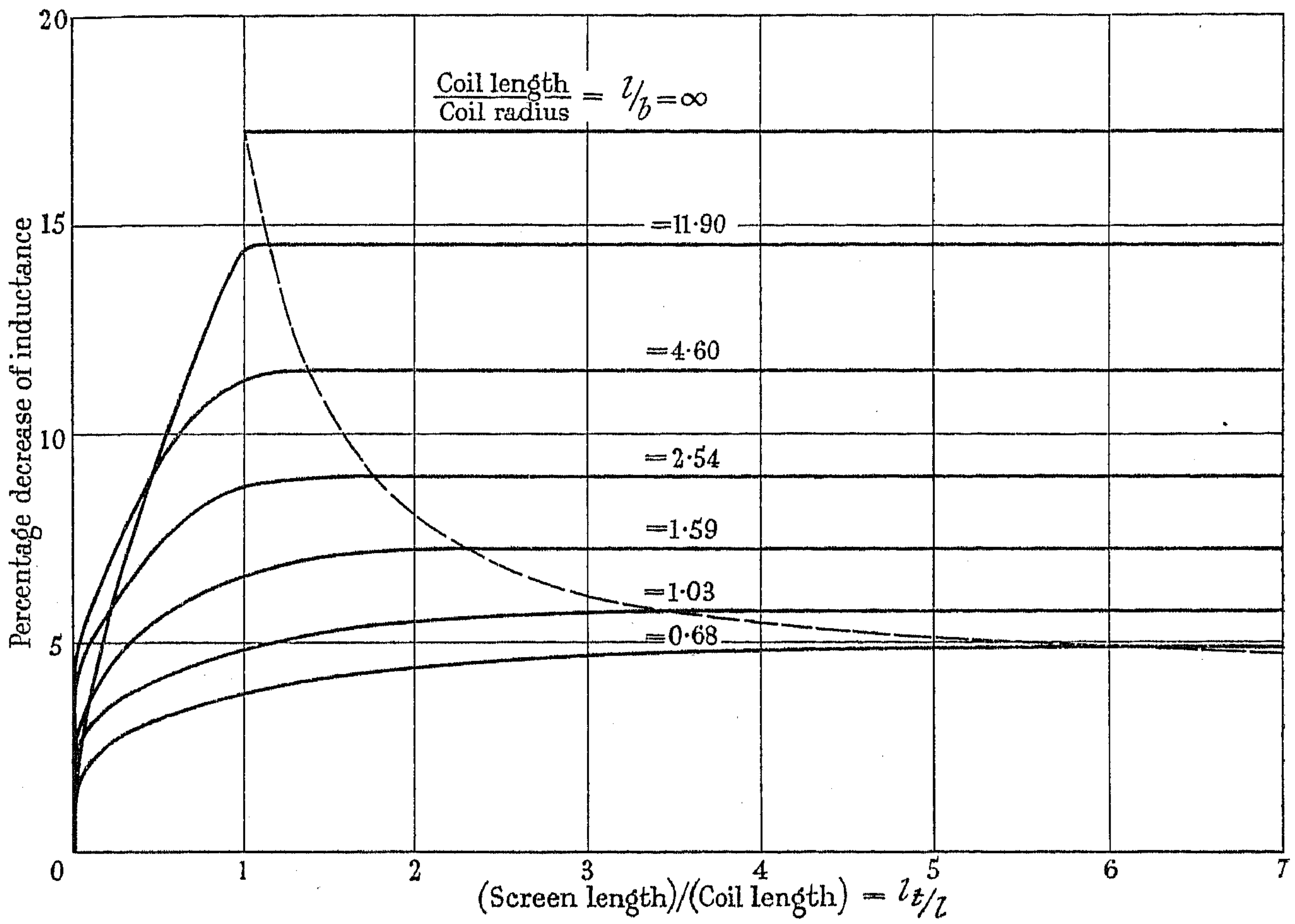

Fig. 4.—Effect of length of screen tube: coils of constant size ($b/a = 0 \cdot 42$) and various shapes.

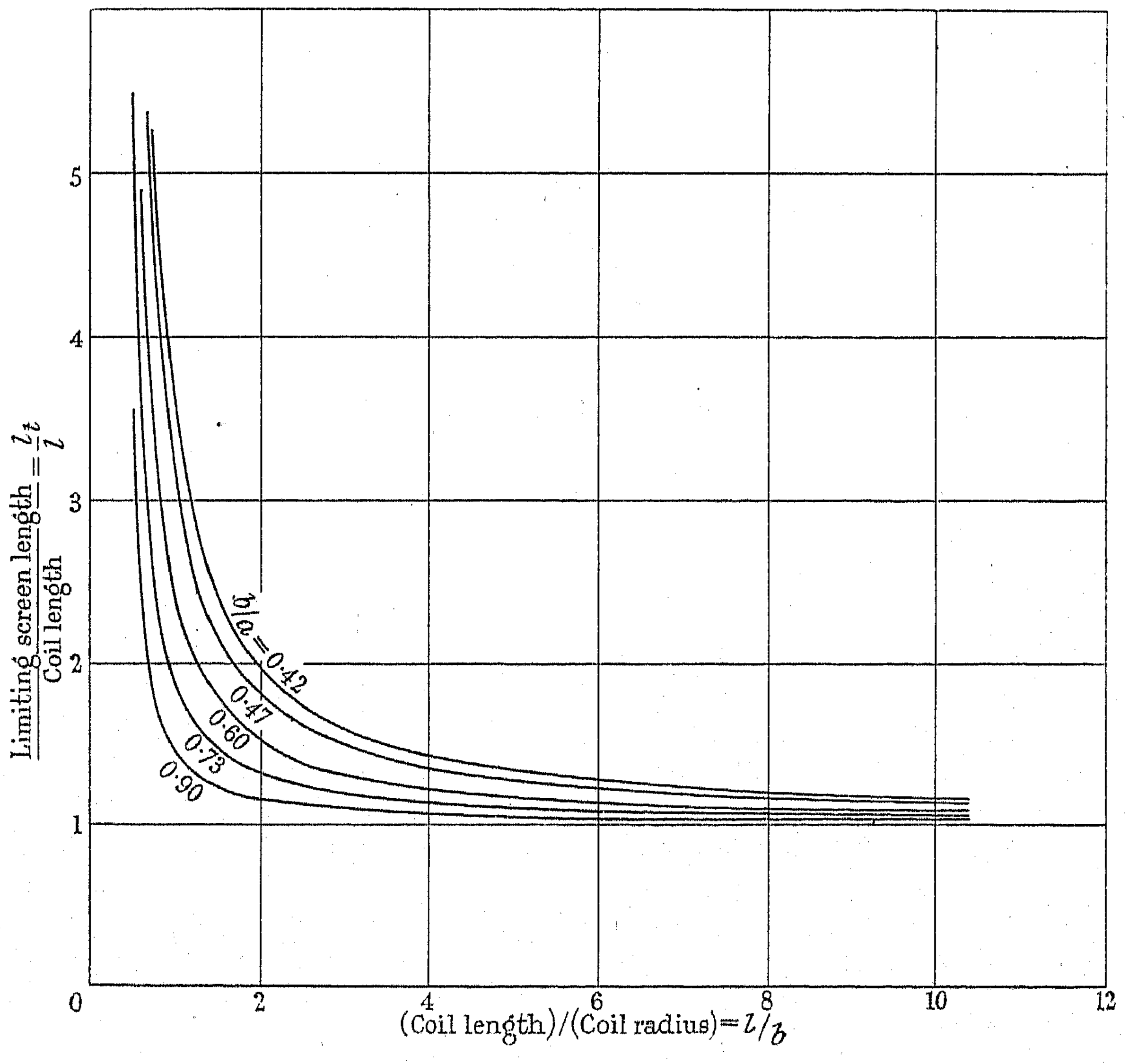

Fig. 5.—Relation between limiting length of screen tube and the shape of the coil: coils of various sizes.

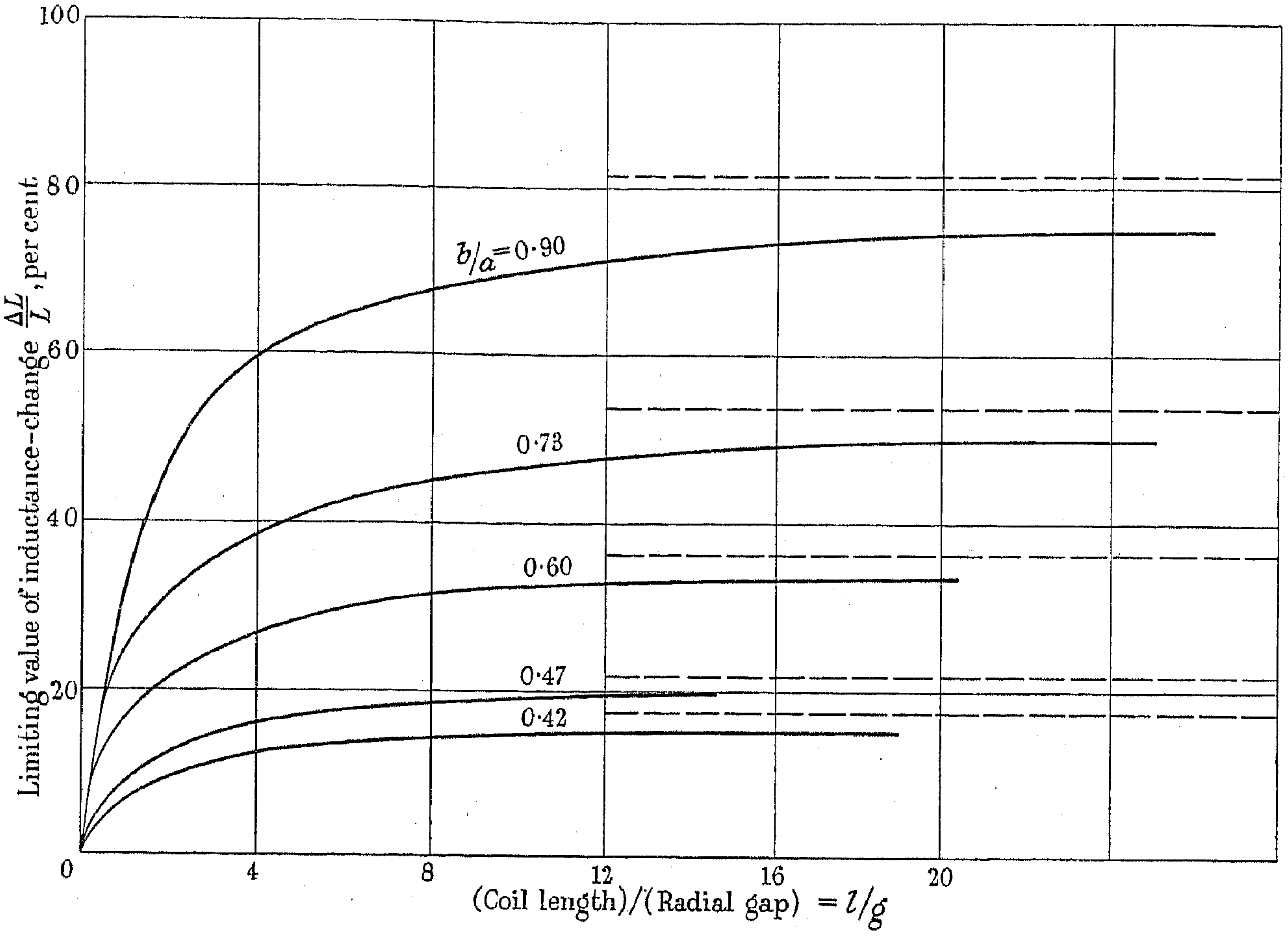

Fig. 6.—Relation between decrease of inductance and l/g for coils of various sizes.

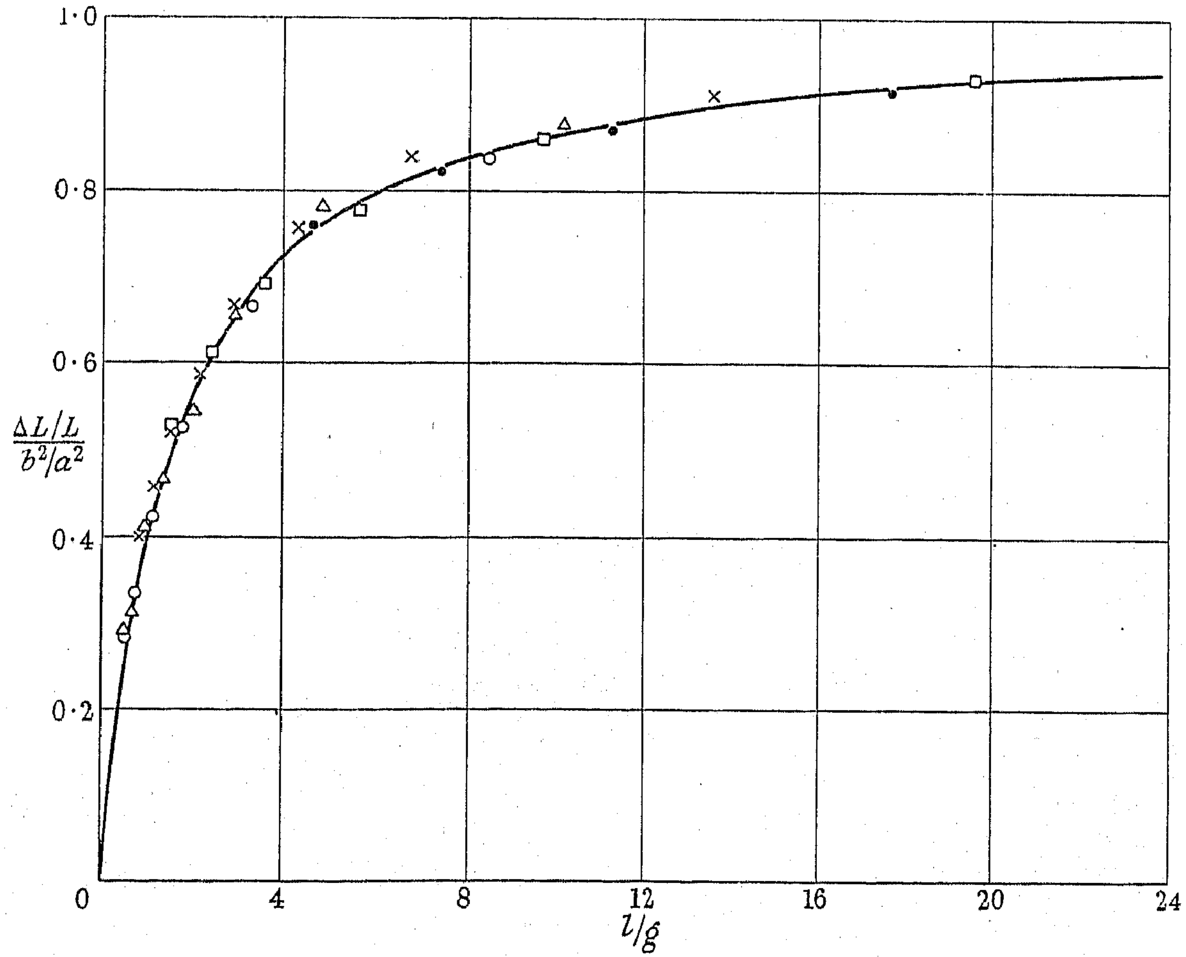

Fig. 7.—Ratio of actual to limiting decrease of inductance as a function of l/g, for coils of all shapes and sizes.

Fig. 5 suggests that the curves cannot differ appreciably from rectangular hyperbolae having the lines $l_t/l = 1$ and $l/b = 0\cdot 38$ as asymptotes, and computation shows that they are represented extremely closely by the equation

$$\left(\frac{l_t}{l} - 1\right)\left(\frac{l}{b} - 0\cdot 38\right) = c$$

where the value of the constant c depends on the size (b/a) of the coil. Further, experience shows that c is a linear function of a/b and that thus the whole family can be represented by the equation

$$\left(\frac{l_t}{l} - 1\right)\left(\frac{l}{b} - 0\cdot 38\right) = \frac{a}{b} - 0\cdot 84 \quad . \quad (11)$$

The length of tube l_t which gives complete screening having thus been found for any coil, it is now instructive to plot this limiting value of $\Delta L/L$ as a function of

$$\frac{l}{a-b} \equiv \frac{l}{g}$$

which is a description of the shape of the coil. The result of doing this is shown in Fig. 6 for each of the five radii: the dotted horizontal lines in this Figure show the corresponding values of b^2/a^2. Fig. 7 shows these five curves replotted but with ordinates expressed as a fraction of b^2/a^2: now all the curves are sensibly coincident. A hyperbolic curve of the form

$$\frac{\Delta L}{L} = \frac{l/g}{(l/g) + B} \cdot \frac{b^2}{a^2}$$

can be found which fits each curve of Fig. 6 within the limits of observation, and the appropriate value of B for each value of b/a is shown in Table 1.

Table 1

b/a	0·42	0·46	0·60	0·72	0·90
B	1·65	1·50	1·40	1·60	1·7

Reference to the approximate treatment in equation (10) will show that this hyperbolic form was foreshadowed in circumstances in which g/a is small, and there the value predicted for B was 1·74. It is surprising that such very rough treatment should turn out to be substantially correct even when g/a is not small, and its success indicates that g/l is always a dominant factor in determining the change of inductance.

Taking a mean value of B from Table 1, the general empirical formula may be written

$$\frac{\Delta L}{L} = \frac{l/g}{(l/g) + 1\cdot 55} \cdot \frac{b^2}{a^2} \quad . \quad . \quad . \quad (12)$$

It is perhaps revolutionary to find that the highly mathematical problem of coil screening can be solved by formula (12), whose very simplicity may cause its generality to be doubted. The results from which it was derived, however, were found for a very wide range of screening conditions, and there can be no doubt that its applicability is equally wide. A high order of accuracy is not expected of the formula, the author being satisfied that as a simple workshop rule it is well adapted to its purpose of predicting (with an accuracy of the order of 2 %) the decrease of inductance of any solenoid when placed inside any cylindrical tube of practical dimensions.*

(3) Effect of Adding Ends to the Screening Tube

We have now found an expression, equation (12), for the change of inductance of a coil inside an open-ended tube of great length and shown also that the change of inductance is sensibly independent of l_t, the length of the tube, provided that l_t is not less than the value given by (11). If the tube is very long there will be no appreciable effect when its ends are closed by conducting plates: but it does not necessarily follow that no appreciable change will result if l_t has the value given by (11); the reason being that the resultant magnetic field is not necessarily zero at all points in the plane of the end of the tube, even though the total flux over the area is zero. Fig. 8 is a typical curve showing $\Delta L/L$ as a function of l_t/l for a tube both with and without ends: it may be seen that when l_t/l is, say, 2·5 then the ends have very little effect. It is desirable to find a simple rule for deciding on a lower limit of l_t/l when equation (12) shall be valid whether or not the tube has ends. Curves such as those of Fig. 8 have been obtained for several different coils, and examination of these has shown that so long as $l_t > (l + 2g)$ then equation (12) is sensibly correct. Thus Table 2 shows collected the values L_2/L_1 calculated from (12), and also the measured values (both with and without ends) for various coils each surrounded by a tube which overhangs its length by a distance g at each end.

Table 2

b	g	l	L_2/L_1, per cent		
cm.	cm.	cm.	From (12)	Measured without ends	Measured with ends
2·36	2·72	2·56	91·8	91·4	90·9
2·36	2·72	4·35	89·0	88·9	88·4
2·36	2·72	7·56	86·1	85·9	85·7
2·36	2·72	12·85	83·7	83·5	83·5
3·71	1·37	4·25	64·5	64·8	63·8
3·71	1·37	8·20	57·7	57·9	56·8
3·71	1·37	19·26	52·0	52·8	52·5

It may be seen that, for the examples shown in the Table, equation (12) suffices to calculate the inductance inside the closed screen to within 1 %. The rule that the overhang shall be at least equal to the gap is extremely simple, and in practice this condition is not likely to be violated: accordingly it is believed that equation (12) gives a valid statement of the change of inductance of any ordinary and practical coil when inside a closed cylindrical screen.

In certain circumstances of mounting it is not uncommon to place coils inside a large cubical box of aluminium: in these circumstances the change of inductance is small, and in all probability could be assessed closely by replacing b^2/a^2 in equation (12) by the corresponding ratio of the areas, provided of course that the above condition—that the ends be a distance not less than g from the ends of the coil—is satisfied. If the ends are closer, the change may be considerably greater than that given by equation (12).

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* It may have been noticed that equation (10) is restricted to $l/a < 1$; this is the case of practical interest because, if $l/a > 1$ and $g/a \ll 1$, it is obvious that the value of $\Delta L/L$ will approach very near to that of b^2/a^2.

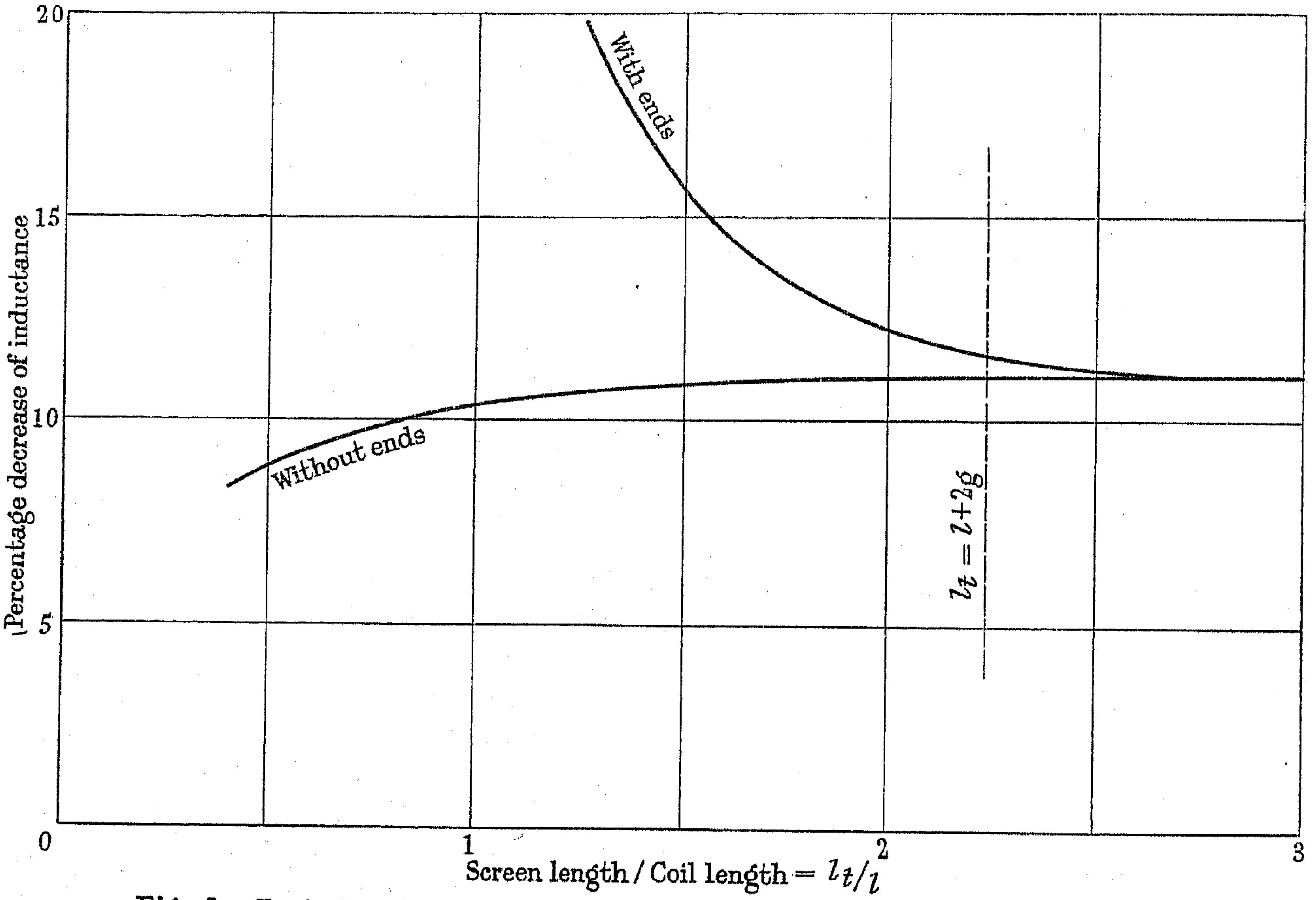


Fig. 8.—Typical curve illustrating the effect of end plates on the screen tube.

(4) Effect of Eccentricity of the Coil

When the coil is concentric with the screen the inductance is a maximum. All maxima, save resonance curves, are blunt and hence it follows that a small eccentricity will have a second-order effect on the inductance. Such changes are outside the order of accuracy contemplated in equation (12), which has been formulated to be the simplest possible guide for estimating the decrease of inductance caused by the screen. But they are not necessarily outside the order of practical importance when constancy has to be considered. Thus it is not impossible that a change of ambient temperature may produce a small displacement of the coil, and it is necessary to assess the order of permanence which may be expected. It follows from symmetry that any given coil which has an inductance L_2 when central in the screen tube will decrease in inductance by an amount δL when the eccentricity of the axis is ϵ, where δL and ϵ are related by an equation of the form

$$\frac{\delta L}{L_2} = A_2\epsilon^2 + A_4\epsilon^4 + \ldots$$

A_2 and A_4 being constants depending on the shape of the coil and the screen. Experience shows that the terms in ϵ^4, etc., are negligible for any value of ϵ which is of practical interest. Values of $\delta L/L_2$ have been determined experimentally for a range of coils, and it has been possible to find an empirical formula expressing A_2 in terms of l, g, a, etc.

Take $$\frac{\delta L}{L_2} = A_2\epsilon^2 = A_2'\frac{\epsilon^2}{g^2}\,\frac{L_2 - L_1}{L_2}$$

where L_1 is the inductance of the coil outside the screen. Fig. 9 shows $A_2'b/a$ plotted as a function of g/l for several coils: it may be seen that all the points lie close to the smooth curve drawn among them, which is the hyperbola

$$A_2'\frac{b}{a} = \frac{0\cdot 535g}{l + g}$$

Hence $$\frac{\delta L}{L_2} = 0\cdot 535\frac{\epsilon^2}{g^2}\,\frac{g}{l + g}\,\frac{a}{b}\,\frac{L_2 - L_1}{L_2} \quad . \quad . \quad (13)$$

A numerical example will help to establish the order of magnitudes represented by (13). Thus let a coil of radius 3·71 cm. and length 2·1 cm. be enclosed in a long tube of radius 5·08 cm., and suppose that accidental circumstances displace it by 0·5 mm. from an initial position very near the axis of the tube. Substitution of these values in (13) gives

$$\frac{A_2'\epsilon^2}{g^2} = \frac{3\cdot 85}{10^4}$$

and substitution in (12) gives

$$\frac{L_1 - L_2}{L_2} = 0 \cdot 36$$

whence

$$\frac{\delta L}{L_2} = -\frac{139}{10^6}$$

This particular numerical example was chosen because it corresponds with the dimensions of one of the coils which was measured. Measurement showed that, when $\epsilon = 5$ mm.,

$$\frac{\delta L}{L_2} = -\frac{13 \cdot 9}{10^3}$$

whereas the value calculated from (13) is also $-13 \cdot 9/10^3$.

The accuracy of the agreement in this particular case is better than the general accuracy to be expected, but in general a very close estimate of the effect on inductance of small radial movements of the coil can be obtained from (13), which may therefore be of considerable value in determining the contribution of these movements to the temperature coefficient of inductance of the coil.

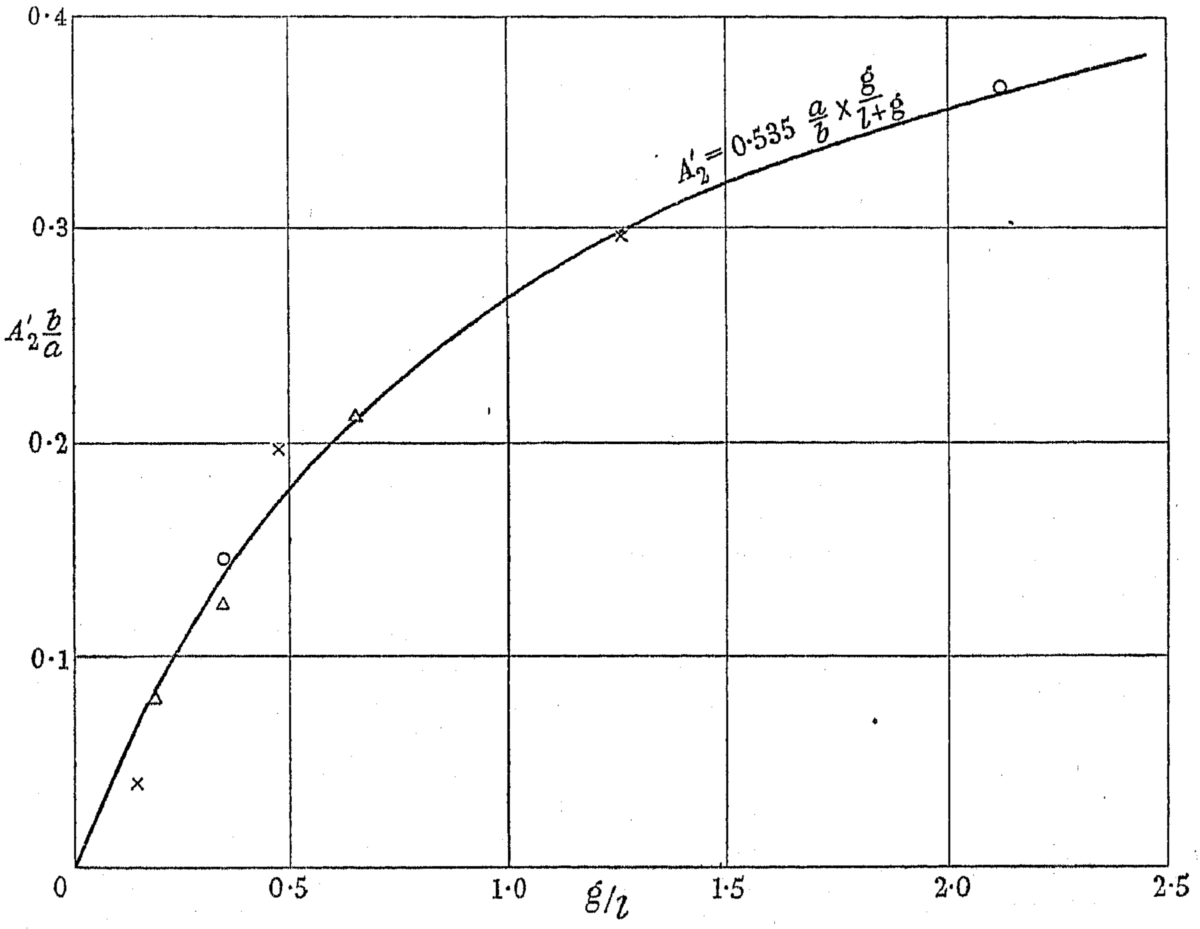


Fig. 9.—Factor for determining the decrease of inductance due to a small eccentricity of the coil.

(5) Effect of Small Axial Displacements in a Closed Screen

A coil 2·36 cm. radius and 4·31 cm. long was placed axially inside a closed cylindrical copper box and the change of inductance was observed as a function of small axial displacement. When the box was of 5·4 cm. radius and 10·7 cm. long, it was found that

$$\frac{\delta L}{L_2} = -\frac{4 \cdot 4}{10^3} y^2$$

y being the axial movement in cm. When the box was of 4·13 cm. radius and 7·8 cm. long it was found that

$$\frac{\delta L}{L_2} = -\frac{12 \cdot 6}{10^3} y^2$$

Thus if y is of the order of 0·5 mm., the decrease of inductance will be of the order of, say, 20 parts in 10^6. It did not seem worth while to derive a general expression for all shapes of coil.

(6) Effect of Ellipticity of Screen Tube

A copper tube 5·08 cm. radius and 20 cm. long was clamped between two mild-steel plates which formed a vice to squash the tube: coils were placed on the axis of the tube, and the change of inductance was measured as the tube was squeezed into an ellipse whose minor semi-axis was 4·73 cm. Two coils were used, one having a radius of 3·06 cm. and length 13·9 cm., the other a radius of 3·71 cm. and length 19·3 cm. In each case the decrease of inductance varied in a substantially parabolic manner with the fractional decrease of the shortest diameter. When this amounted to 7 % the screened inductance of the first coil had decreased by 5·0 parts in 10^3, and that of the second by 5·7 parts in 10^3. One may perhaps suggest that, for coils of practical dimensions,

$$\frac{\delta L}{L_2} \simeq \frac{\delta^2}{10^4}$$

where δ is the percentage decrease of diameter.

The previous three Sections of the paper are concordant common to place coils inside a large cubical box of aluminium: in these circumstances the change of inductance is small, and in all probability could be assessed closely by replacing b^2/a^2 in equation (12) by the corresponding ratio of the areas, provided of course that the above condition—that the ends be a distance not less than g from the ends of the coil—is satisfied. If the ends are closer, the change may be considerably greater than that given by equation (12).

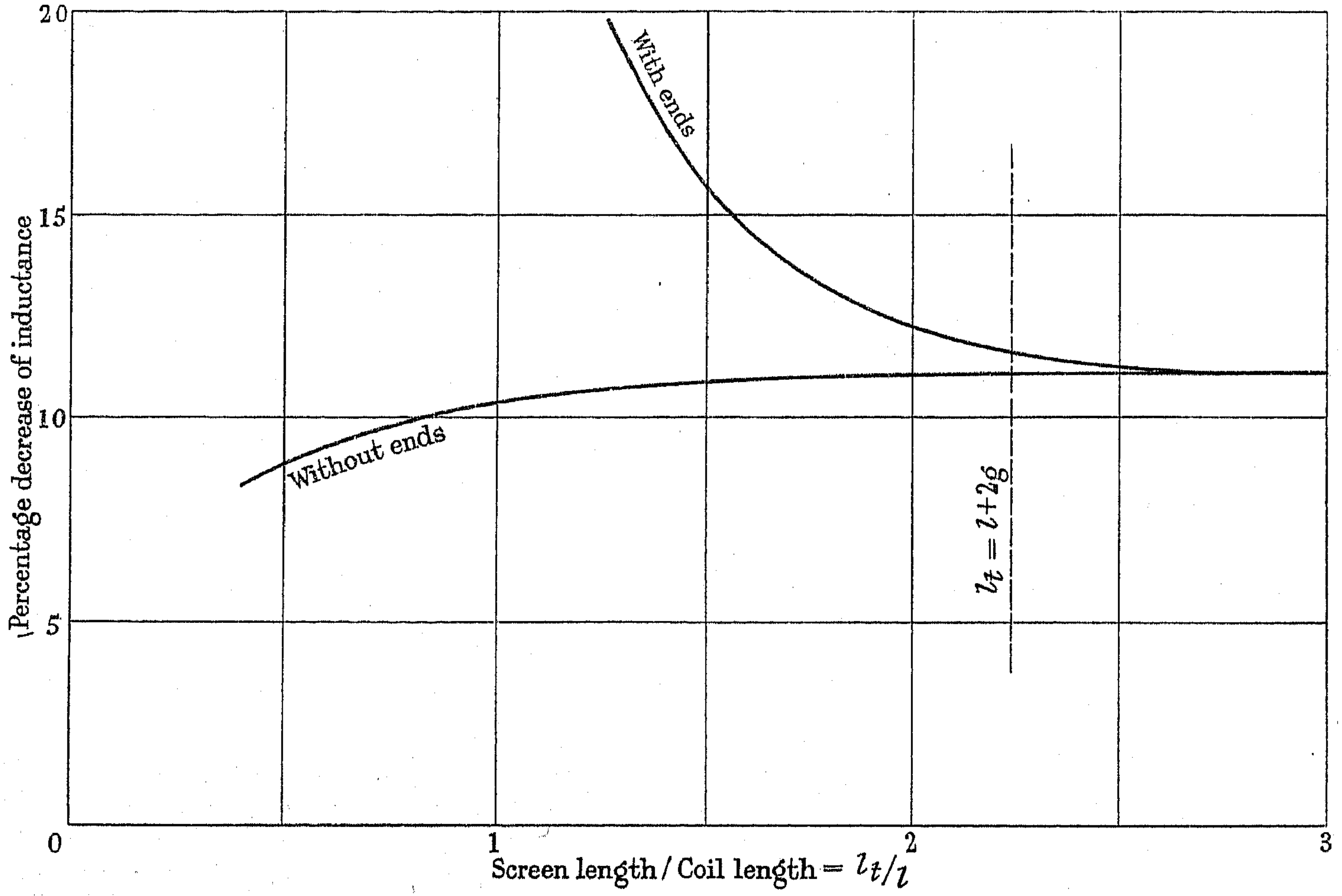


Fig. 8.—Typical curve illustrating the effect of end plates on the screen tube.

(4) Effect of Eccentricity of the Coil

When the coil is concentric with the screen the inductance is a maximum. All maxima, save resonance curves, are blunt and hence it follows that a small eccentricity will have a second-order effect on the inductance. Such changes are outside the order of accuracy contemplated in equation (12), which has been formulated to be the simplest possible guide for estimating the decrease of inductance caused by the screen. But they are not necessarily outside the order of practical importance when constancy has to be considered. Thus it is not impossible that a change of ambient temperature may produce a small displacement of the coil, and it is necessary to assess the order of permanence which may be expected. It follows from symmetry that any given coil which has an inductance L_2 when central in the screen tube will decrease in inductance by an amount δL when the eccentricity of the axis is ϵ, where δL and ϵ are related by an equation of the form

$$\frac{\delta L}{L_2} = A_2\epsilon^2 + A_4\epsilon^4 + \ldots$$

A_2 and A_4 being constants depending on the shape of the coil and the screen. Experience shows that the terms in ϵ^4, etc., are negligible for any value of ϵ which is of practical interest. Values of $\delta L/L_2$ have been determined experimentally for a range of coils, and it has been possible to find an empirical formula expressing A_2 in terms of l, g, a, etc.

Take $$\frac{\delta L}{L_2} = A_2\epsilon^2 = A_2'\frac{\epsilon^2}{g^2}\,\frac{L_2 - L_1}{L_2}$$

where L_1 is the inductance of the coil outside the screen. Fig. 9 shows $A_2'b/a$ plotted as a function of g/l for several coils: it may be seen that all the points lie close to the smooth curve drawn among them, which is the hyperbola

$$A_2'\frac{b}{a} = \frac{0\cdot535g}{l+g}$$

Hence $$\frac{\delta L}{L_2} = 0\cdot535\frac{\epsilon^2}{g^2}\,\frac{g}{l+g}\,\frac{a}{b}\,\frac{L_2 - L_1}{L_2} \quad . \quad . \quad (13)$$

A numerical example will help to establish the order of magnitudes represented by (13). Thus let a coil of radius 3·71 cm. and length 2·1 cm. be enclosed in a long tube of radius 5·08 cm., and suppose that accidental circumstances displace it by 0·5 mm. from an initial position very near the axis of the tube. Substitution of these values in (13) gives

$$\frac{A_2'\epsilon^2}{g^2} = \frac{3\cdot85}{10^4}$$

and substitution in (12) gives

$$\frac{L_1 - L_2}{L_2} = 0\cdot36$$

whence

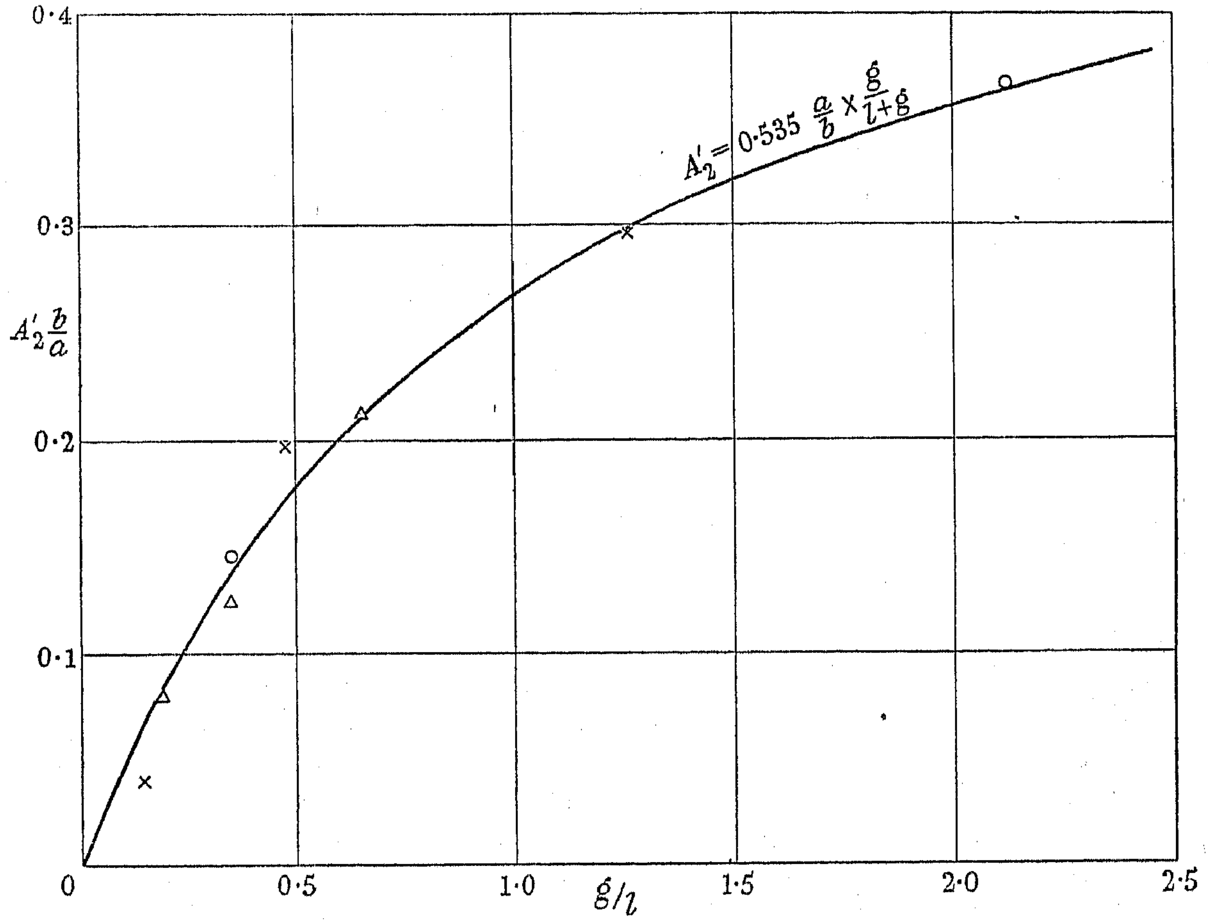
$$\frac{\delta L}{L_2} = -\frac{139}{10^6}$$

This particular numerical example was chosen because it corresponds with the dimensions of one of the coils which was measured. Measurement showed that, when $\epsilon = 5$ mm.,

$$\frac{\delta L}{L_2} = -\frac{13\cdot9}{10^3}$$

whereas the value calculated from (13) is also $-13\cdot9/10^3$.

The accuracy of the agreement in this particular case is better than the general accuracy to be expected, but in general a very close estimate of the effect on inductance of small radial movements of the coil can be obtained from (13), which may therefore be of considerable value in determining the contribution of these movements to the temperature coefficient of inductance of the coil.



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$$\frac{\delta L}{L_2} \simeq \frac{\delta^2}{10^4}$$

where δ is the percentage decrease of diameter.

The previous three Sections of the paper are concordant with the well-known principle that the inductance of any coil is insensitive to small changes in the shape of its cross-section.*

(7) Temperature Coefficient of Screened Coils

The present author has not made any direct measurements of the temperature coefficient of screened coils, but it is possible to forecast how the screen will affect this parameter. If both the coil and the screen are of copper and the coil is free to expand (not restricted by a former) and the temperature is uniform throughout, then the temperature coefficient of the screened coil will be equal to the coefficient of linear expansion of copper, namely 17 parts in 10^6 per degree Centigrade. If the temperature change is accompanied by any deformation of the coil or of the screen, or by a displacement of the coil within the screen, then the temperature coefficient will be reduced by such deformations: the possible order of such decrease can probably be assessed from the foregoing three Sections.

In practice it is probable that the coil and the screen will not be at the same temperature. It follows from (12), after considerable reduction, that

$$ {}_{\tau}L_2 \simeq {}_0L_2 \left\{ 1 + \alpha \left[\tau_1 - \frac{\left(2 + \dfrac{1 \cdot 55a}{l + 1 \cdot 55g}\right)(\tau_1 - \tau_2)}{\dfrac{a^2}{b^2}\left(1 + \dfrac{1 \cdot 55g}{l}\right) - 1} \right] \right\} \quad (14) $$

where α is the coefficient of linear expansion of the metal of both coil and screen, τ_1 the temperature of the coil and τ_2 the temperature of the screen. In general, a/l is near unity, g/l is near $\frac{1}{2}$ and a/b is near 2: so we may write

$$ {}_{\tau}L_2 \simeq {}_0L_2 \left[1 + \alpha\left(\tau_1 - \frac{\tau_1 - \tau_2}{2}\right) \right] \quad . \quad . \quad (15) $$

Thus 1 deg. C. difference of temperature will change the inductance by about 9 parts in 10^6, and the change will be negative if the coil is hotter than the screen.

These calculations have ignored the inductance due to magnetic field inside the wire of the coil and inside the metal of the screen. It is known† that the field within the wire may cause the temperature coefficient to be much greater than α when the radius r of the wire is such that the well-known parameter

$$ z \equiv \sqrt{\left(\frac{8\pi^2 f r^2}{\rho}\right)} $$

is greater than about 2 and less than about 30.

This effect need not be considered further here, but it is necessary to consider the similar effect in the screen tube. We see that the term b^2/a^2 in equation (12) should be multiplied by $(1 + x'^2)^{-1}$, where $x'^2 = \dfrac{\rho}{4\pi^2 a^2 f}$ [see equation (6)]. The temperature coefficient of x'^2 is sensibly equal to β, the temperature coefficient of resistivity. Hence the term in b^2/a^2 is more correctly written as

$$ \left(\frac{b^2}{a^2}\right)_{\tau} = \left(\frac{b^2}{a^2}\right)_0 \left[1 + 2\alpha(\tau_1 - \tau_2) - \beta x'^2 \tau_2\right] \quad . \quad (16) $$

If $a = 5$ cm., then for copper $x'^2 < 1 \cdot 68/10^5$ if $f > 100$ kc./s.: since $\beta = 3 \cdot 6/10^3 = 200\alpha$, it follows that $\beta x'^2$ is less than $(3 \cdot 36/10^3)\alpha$ for all frequencies greater than 100 kc./s. Thus it is clear that the resistance effect cannot modify appreciably the temperature coefficient of the screen. On the other hand, if the screened coil forms part of a self-maintained valve generator, it is conceivable that the temperature change of resistance of the screen may cause a larger change of frequency than would be anticipated from the foregoing; because the change of temperature of the screen will modify the effective resistance of the screened coil and can thereby produce an indirect change of frequency which is inappreciable only if the power factor of the screened coil is small. For example, if an aluminium screening plate in the neighbourhood of a coil were inadvertently replaced by an iron plate, no sensible change of inductance would result but there would be an appreciable increase of resistance and this increment would have a temperature coefficient of the order of $\frac{1}{2}\beta$. A noticeable increase in the temperature coefficient of frequency might thus be produced indirectly.

PART 3

INCREASE OF RESISTANCE

(1) General

We have seen that the inductance is decreased by the induced currents flowing circumferentially round the tube: such currents heat the tube, and this dissipation of power causes an increase in the apparent resistance of the coil. In considering the problem of power loss in the screen it is essential to realize that the magnitude and distribution of current induced in the screen is almost independent of the resistivity of the material, depending almost entirely on the shape and size of the tube: this has been discussed analytically in Part 1, Section (2). Consequently the apparent increase of resistance of a coil in a screen of given shape is proportional to the effective resistivity of the screen material: in all practical cases the apparent resistivity varies as $\sqrt{(\rho f)}$ and is independent of the thickness of the metal [see equation (6)].

Since both the decrease of inductance and the increase of resistance are due to the currents induced in the screen, it is reasonable to expect a simple relation between the two. As in Part 1 and Fig. 1, consider a long solenoid inside a long tube: then, as before [see equation (1)],

$$ I = iUb^2/a^2 $$

Hence the loss in the screen is

$$ P = I^2 \times 2\pi a \rho m \text{ per unit axial length} $$

$$ = i^2 U^2 \frac{b^4}{a^4} 2\pi a \rho m \text{ per unit axial length} $$

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* See, for instance, E. B. MOULLIN: *Proceedings of the Institute of Radio Engineers*, 1935, **23**, p. 71.

† See H. A. THOMAS: *Journal I.E.E.*, 1939, **84**, p. 101; and E. B. MOULLIN: *Proceedings of the Institute of Radio Engineers*, 1938, **36**, p. 1385.

Hence the increment of coil resistance is

$$R' = 2\pi a\rho m U^2 \frac{b^4}{a^4} \quad . \quad . \quad . \quad . \quad (17)$$

We have seen in equation (2) that for a long coil $\Delta L/L = b^2/a^2$, and hence we can write

$$R' = \left(\frac{U\Delta L}{L}\right)^2 \times 2\pi a\rho m \text{ per unit length of coil} \quad (18)$$

$$\text{or} \quad R' = \frac{\Delta L}{L}\left(\frac{Ub}{a}\right)^2 \times 2\pi a\rho m \text{ per unit length of coil} \quad (19)$$

When a coil has a finite length the circumferential current induced in the tube will be much greater near the middle of the coil than at a point beyond its end, and the energy loss in unit length of the tube is not constant. Thus, for example, consider a band of wires distant g from a conducting plane, a system illustrated in Fig. 2 which is, as we have seen already, a close representation of a coil whose diameter is not much less than that of the screen. It is well known that the magnetic field on the axis of such a band and its image, and at the mid-point of its length, is

$$H = 8iU \operatorname{arc\,tan} \frac{l}{2g}$$

Hence at this point the line density (σ_0) of the current induced in the infinite conducting plane must have the value given by $H = 4\pi\sigma_0$. Therefore

$$\sigma_0 = \frac{2iU}{\pi} \operatorname{arc\,tan} \frac{l}{2g}$$

The power loss in the plane will be proportional to $\int_{-\infty}^{+\infty} \sigma^2 dx$. Let

$$\int_{-\infty}^{+\infty} \sigma^2 dx \equiv N^2 \sigma_0^2 l$$

The value of N^2 for various values of l/g must be found by graphical integration: this process has yielded the results shown in Table 3.

Table 3

l/g	2	4	8	16	∞
N^2	1·125	0·888	0·864	0·892	1·0

This Table shows that for values of l/g of practical interest, N^2 is substantially constant and not far from unity: thus there is reason to hope that an empirical formula can be found for R' which will be independent of the shape of the coil except in so far as this has dictated the value of $\Delta L/L$. It has been shown in Part 1, Section (3), that $\Delta L/L$ for a finite coil can be predicted successfully by likening it to a flat band near a plate. Extending this concept to the increment of resistance, we should have

$$\begin{aligned} R' &= N^2\sigma_0^2 l \times 2\pi a\rho m \\ &= 0{\cdot}758 U^2 \rho m \times 2\pi a l, \text{ when } l/g = 16 \quad . \quad (20) \end{aligned}$$

Also, when $l/g = 16$, equation (8) gives

$$\frac{\Delta L}{L} = 1 - \frac{2g}{b}\left(1 + 0{\cdot}868\frac{b}{l}\right)$$

If $a = 5$ and $l = 2{\cdot}5$, then $g = 0{\cdot}156$ and $b = 4{\cdot}84$; and then $\Delta L/L = 0{\cdot}827$ and

$$\frac{b^2}{a^2}\frac{\Delta L}{L} = 0{\cdot}776$$

Then for this case equation (19) becomes

$$R' = 0{\cdot}776 U^2 \rho m \times 2\pi a l$$

which differs by only 2·4 % from the value given by (20), suggesting that (19) should be substantially correct in most practical cases.

(2) Method of Measuring Resistance: Details of Coils and Screens

The ordinary methods of measuring high-frequency resistance are inconvenient when the coil is enclosed in a screen. A convenient method is to use the screened coil as the inductance of a dynatron generator which is adjusted to be on the threshold of oscillation. Then the dynamic resistance of the circuit is equal to the negative slope of the dynatron characteristic, which can be found and calibrated. The calibration of the dynatron characteristic was performed at 50 c./s. by the dynamometer method.* The dynatron consisted of two Mazda AC/S2 valves in parallel, and these provided any value of negative resistance down to 2·5 kilohms. It is hoped to describe the details of the dynatron apparatus elsewhere: suffice it to say here that the calibration was checked from day to day and there are strong grounds for believing that the results obtained are as accurate and reliable as precision measurements of resistance by more classical methods.

However, whatever method is used, it can measure only the total resistance of the circuit, which is due partly to i^2R losses in the coil and screen and partly to dielectric losses in the coil former, tuning condenser and measuring apparatus. We are concerned here only with the first component, but the existence of the second causes much trouble in interpreting the measurements. The realization and clear understanding of this fact is so essential to what follows that it seems wise to insert here a short discussion of the problem. If a coil of inductance L had a resistance R independent of frequency, then $F \equiv R/(\omega L)$ would increase in proportion to the wavelength λ. Since, however, R increases in proportion to the square root of the frequency (i.e. presuming $z > 3$), it follows that $F \propto \lambda^{1/2}$. Hence the curve relating F (for the coil) with λ must have the form shown by Curve (2) in Fig. 10. But experience shows that the curve relating F (for any *circuit*) with λ is typified by Curve (3) in Fig. 10, and there is always a minimum value at some wavelength. Suppose now that at some wavelength OA in Fig. 10 the measured value of F is represented by AC; then a portion AB, always in fact unknown in value, is due to the coil conductors and the remainder BC is due to dielectric losses somewhere in the circuit. It will be clear from Fig. 10 that the very existence of a minimum value of F demonstrates the presence of dielectric losses. And it follows that at all wavelengths less than that at which F is a minimum, the dielectric loss is a dominant component of F.

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* See D. A. Bell: *Journal I.E.E.*, 1935, **76**, p. 415.

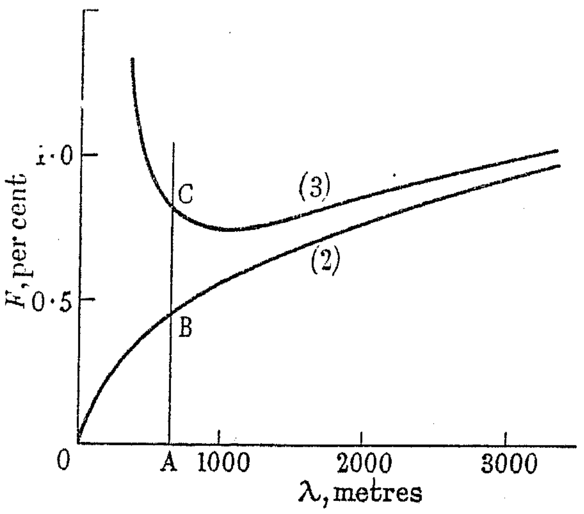

Fig. 10.—Diagram to illustrate the effect of dielectric loss on the power factor of an *LRC* circuit.

When a coil is put inside a screen the component of resistance corresponding to AB will be increased, but the portion corresponding to CB will probably not be changed. Any observed increment of resistance is most probably equal to the increment due to losses in the screen; but this cannot be expressed as a fraction of the resistance of the coil itself, since this is unknown. The effect on F, however, is more intricate. The circuit capacitance consists of a part C_1 due to the tuning condenser, which probably is substantially free of loss, together with stray capacitances C_2 whose power factor F_2 is likely to be comparatively large. Then the dielectric power-factor F' will be equal to $\frac{C_2}{C_1 + C_2}F_2$, and it is this which is represented by the intercept BC in Fig. 10. When the coil is placed in the screen, it is necessary to increase C_1 to some value C_1' so as to compensate for the decrease of inductance: Then the dielectric power-factor will be given by

$$F'' = \frac{C_2}{C_1' + C_2}F_2$$

and thus F'' is less than F'. Hence it follows that at any wavelength less than that for which the power factor F of the unscreened circuit is a minimum, the circuit power-factor will probably be decreased by screening the coil, notwithstanding that the power factor of the coil itself has been increased by the screen.

The two experimental curves in Fig. 11 demonstrate the reality of this effect.

Thus it was essential to find a means of separating the resistance due to the screen from the total resistance of the whole circuit. This can be done by changing the specific resistance of the screen, since this will alter only the losses in the screen.* For this purpose two long tubes, each 3·8 cm. internal diameter, were obtained; one was of electrolytic copper (resistivity 1 680 c.g.s. units) and the other of brass (resistivity 6 950 c.g.s. units).

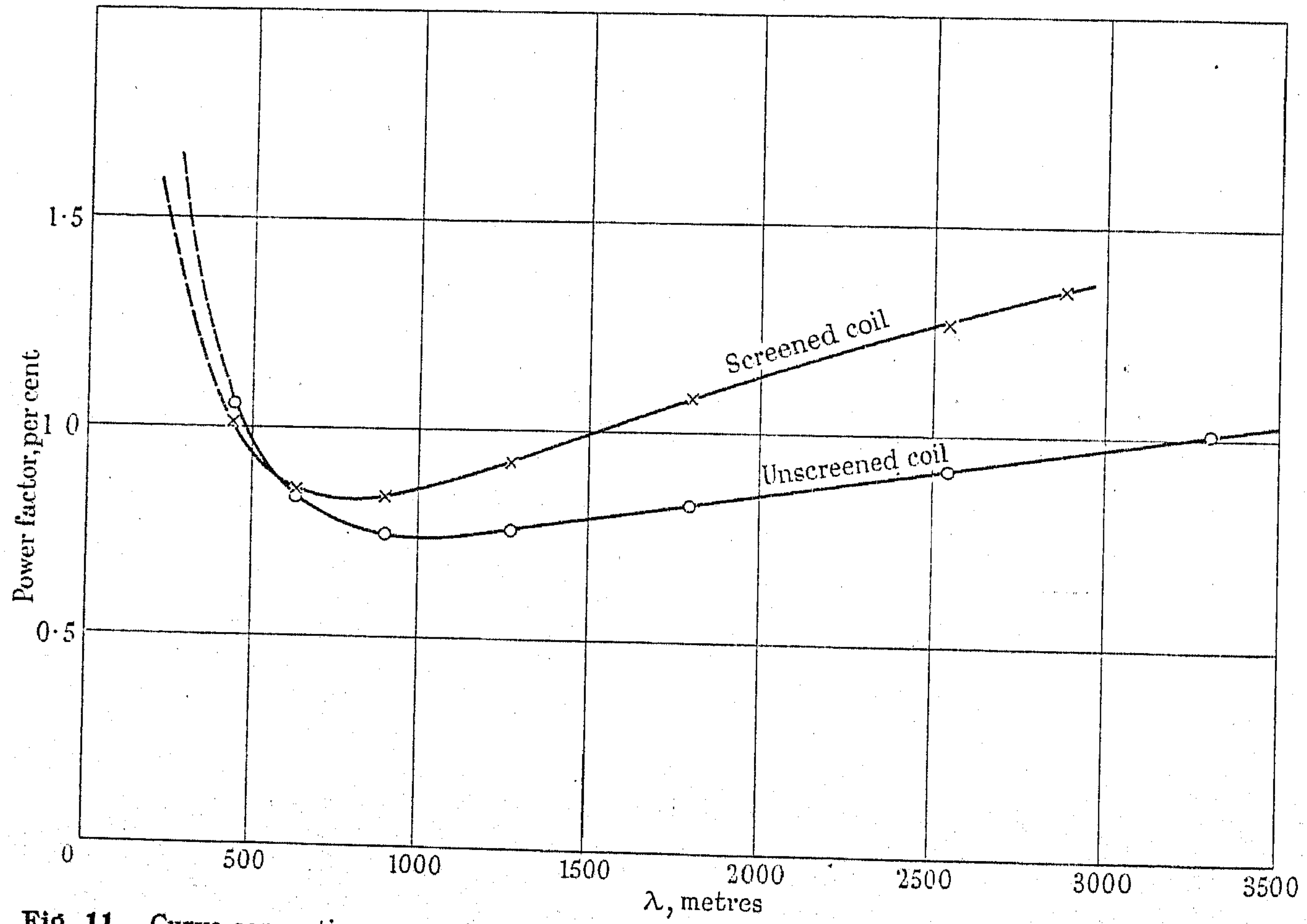

Fig. 11.—Curve connecting power factor and wavelength for a certain coil when isolated and when enclosed in a screening can.

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* Cf. E. B. Moullin: *Proceedings of the Royal Society*, A, 1932, **137**, p. 116; W. Jackson: *Proceedings of the Institute of Radio Engineers*, 1934, **22**, p. 957; and W. Jackson: *Journal I.E.E.*, 1937, **80**, p. 440.

Substitution in equation (6) shows that for frequencies greater than 25 kc./s. the effective thickness of both materials differs insensibly from $1/m$, and hence the difference in their thicknesses (1·8 mm. and 3·4 mm.) was irrelevant. Since both screens produced exactly the same decrease in the inductance of any given coil, the condenser setting was the same for both, and hence the dielectric power-factor of the circuit was the same whether the coil was in the brass or the copper tube. Coils whose length ranged from 2·58 cm. to 15·7 cm. were wound on formers having radii of 1·62, 2·36 and 3·06 cm.: the length of the tube was such that for all coils it may be regarded as infinite [see equation (11)].

The circuit resistance was measured at various frequencies when the coil was unscreened and when it was enclosed in the copper tube, and also in the brass tube. The increment of coil resistance due to the screen can be deduced from the last two measurements.

Fig. 12 shows the circuit resistance plotted against $\log f$ for a coil of 2·36 cm. radius and 12·85 cm. long: in this Figure, Curve 1 relates to the unscreened coil, Curve 2 to the coil in the brass tube, and Curve 3 to the coil in the copper tube.

The increment of resistance R' of a given screened coil must vary as $\sqrt{(\rho f)}$, where ρ is the resistivity of the screen. Hence if the suffixes B and C denote brass and copper respectively it follows that

$$R_B' - R_C' \propto (\sqrt{\rho_B} - \sqrt{\rho_C})\sqrt{f} \quad . \quad . \quad (21)$$

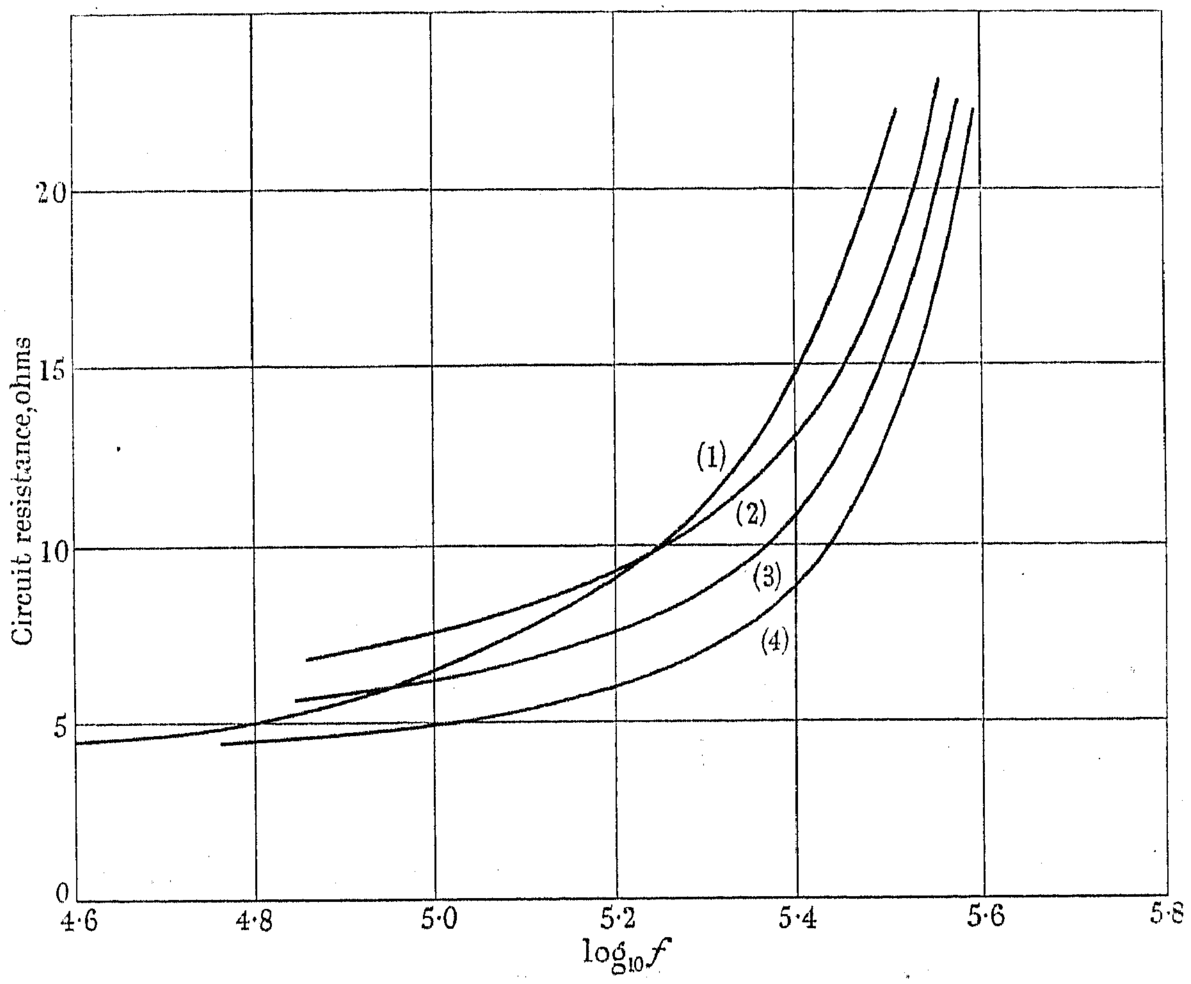

Fig. 12.—Circuit-resistance/log f curve for a coil in which $l/b = 5\cdot45$.

Curve (1). Coil unscreened. Curve (2). Brass screen, $b/a = 0\cdot62$. Curve (3). Copper screen, $b/a = 0\cdot62$. Curve (4). Derived from (3) and (2).

For a given value of f,

$$\frac{R_C'}{\sqrt{\rho_C}} = \frac{R_B'}{\sqrt{\rho_B}} = \frac{R_B' - R_C'}{\sqrt{\rho_B} - \sqrt{\rho_C}}$$

$$\therefore \quad R_C' = \frac{\sqrt{\rho_C}}{\sqrt{\rho_B} - \sqrt{\rho_C}}(R_B' - R_C') \quad . \quad . \quad (22)$$

Now $(R_B' - R_C')$ must be equal to the difference between corresponding ordinates of Curves 2 and 3 in Fig. 12, and hence R_C' can be deduced by means of equation (22). Curve 4 is obtained by subtracting from Curve 3 the values of R_C' so found; this curve relates the circuit resistance with frequency for the given coil if enclosed in a screen of zero resistivity.

Equation (21) shows that if the measured values of $(R_B' - R_C')$ are plotted against $\sqrt{f}$ the result should be a straight line through the origin.* This has been done in Fig. 13 for the differences taken from Fig. 12, and the points lie close to a straight line which has been drawn. If equation (19) is valid, it follows that

$$R_B' - R_C' = \frac{\Delta L}{L}\left(\frac{Ub}{a}\right)^2 \times 2\pi a l(\rho_B m_B - \rho_C m_C) \quad (23)$$

For the relevant values of ρ,

$$\rho_B m_B - \rho_C m_C = 0\cdot266\sqrt{f} \times 10^{-6}$$

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* Provided, of course, that this is done only for values of f greater than 25 kc./s.

For this coil the observed value of $\Delta L/L$ has been substituted in equation (23), and the straight line resulting is that plotted in Fig. 13. That the points lie close to a line through the origin is inevitable, that they lie close to the particular line which has been drawn shows that equation (19) for R' is substantially correct, at least for the shape and size of coil to which Fig. 12 refers. Curves corresponding to 1, 2 and 3 of Fig. 12 were obtained for a wide variety of shapes and sizes of coil: for each coil the derived curve corresponding to Fig. 13 showed that equation (19) is correct to a degree of accuracy sufficient for all ordinary purposes.

The author believes that the resistance of any coil of dimensions of practical interest is increased by a screen by an amount which differs very little from that given by equation (19), namely

$$R' = \frac{\Delta L}{L}\left(\frac{Ub}{a}\right)^2 \times 2\pi a\rho m \text{ per unit length of coil}$$

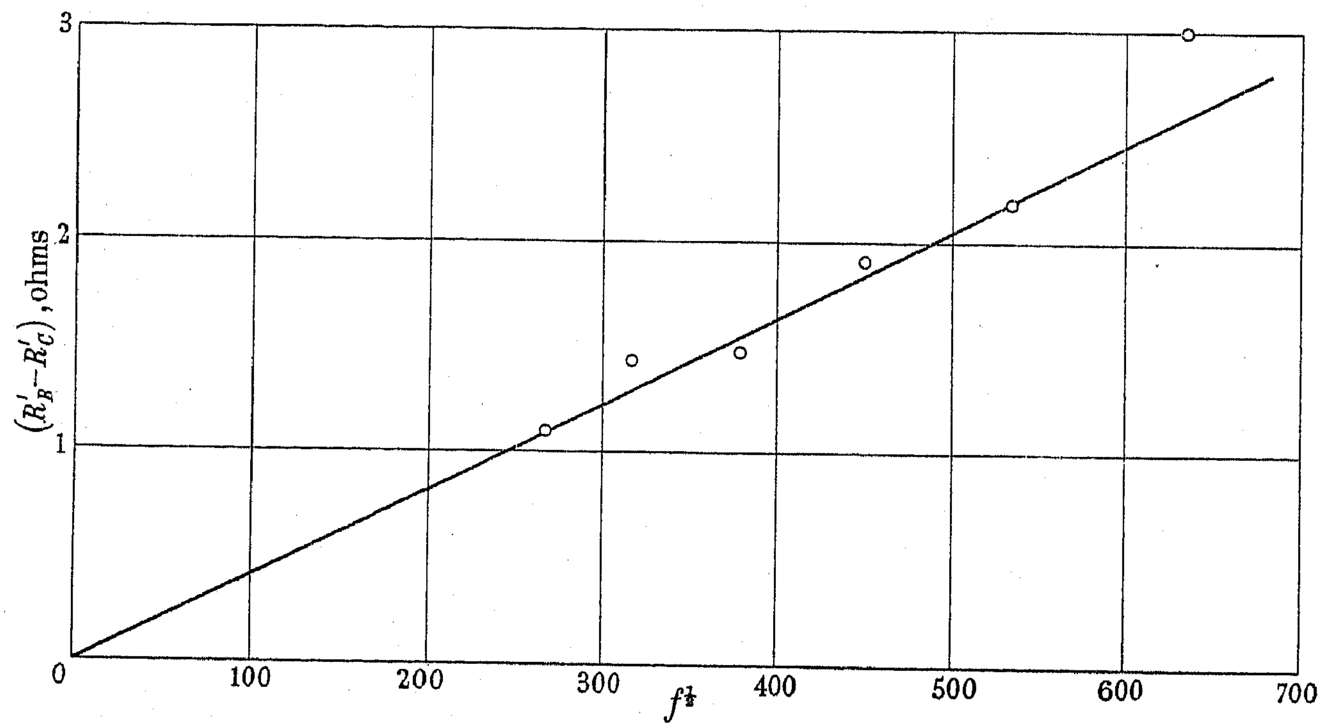

Fig. 13.—Difference between values of circuit resistance added by brass and copper screen tubes, plotted against $f^{\frac{1}{2}}$.
The straight line represents the relation calculated from equation (23).

It is seen to be a formula of very convenient simplicity, and it depends for the value of $\Delta L/L$ upon equation (12), which is equally simple. Its inherent expectation of success has been demonstrated by simple theory, and amply justified by the experimental verification which has been obtained.

(3) Increment of Coil Power-Factor due to the Screen

It has been remarked in the previous Section that whilst the screen produces an increase of effective coil resistance, it also tends to decrease the dielectric power-factor of the circuit if the frequency is maintained constant. Hence the power factor of the whole circuit is a somewhat indefinite quantity and the exact effect of the screen upon it cannot be evaluated, unless the frequency is much less than that which gives minimum power-factor in the absence of the screen, in which case dielectric losses make a very small contribution to the circuit power-factor.

But the effect of the screen on the coil alone can be readily evaluated, as follows: If F is the power factor of the unscreened coil at a given frequency, it follows that the power factor F' of the screened coil is given by the expression

$$F' = \frac{F}{1-(\Delta L/L)} + \frac{R}{\omega L[1-(\Delta L/L)]}$$

$$= \frac{1}{1-(\Delta L/L)}\left[F + \frac{\Delta L}{L}\,\frac{1+0\cdot868b/l}{2\pi a}\sqrt{\left(\frac{\rho}{f}\right)}\right]$$

from (12) and (19),

$$= \frac{1}{1-(\Delta L/L)}\left(F + \frac{\Delta L}{L}\,\frac{1+0\cdot868b/l}{4\cdot8a\sqrt{f_{kc./s.}}}\right)$$

for a screen of electrolytic copper.

Hence if $\Delta L/L$ is about $\frac{1}{4}$, the increment of coil power-factor will be of the order of $10(a\sqrt{f_{kc./s.}})$ per cent: in practice, a will tend to get less as f increases, and perhaps one may suggest that the increment of coil power-factor due to the electrolytic copper screen is likely to be between 1 and 2 tenths per cent.

PART 4

DISTRIBUTION OF CURRENT IN THE SCREEN

A number of different lines of approach present themselves to the experimenter or the engineer who finds himself faced with the problem of the change of inductance and resistance of a coil enclosed in a screen. The changes of both quantities are closely dependent on the distribution of the eddy currents in the screen, and it seems worth while to include in this paper a section dealing with the methods used by the author in estimating this distribution. It is a record of the simple approximations which are available, a guide to others who may have to deal with similar problems, and an additional justification of the results recorded in the previous Sections.

The curve relating the line-density of induced current with the distance along the axis of the screen tube must be symmetrical about the maximum ordinate, which will be at the mid-point of the coil length, and it must drop to zero beyond the ends of the coil.

(1) Method of Sub-division

The distribution curve can be calculated approximately, following the method and notation used by J. Hak,* as follows. If the resistivity of the tube were zero, then the net flux through every cross-section of it would be zero. Let the screen tube be considered to be divided into $2n$ equal coaxial rings.

Then $l_0 = \Phi_0 a =$ self-inductance of each ring; $m_{\nu-\mu} = \Phi_{\nu-\mu} a =$ mutual inductance between the νth and μth rings; $M_\nu = m_\nu a =$ mutual inductance between the νth ring and the coil; and $I_\nu =$ current in the νth ring. From Part 1 of the paper it is seen that the resistance of the screen can be neglected, and the equation of the current in the νth section becomes

$$I_\nu(l_0 + m_{2n-\nu+1}) + \sum_{\mu=1}^{n}(m_{\nu-\mu} + m_{2n+1-\mu-\nu})I_\mu + M_\nu i = 0 \quad . \quad (24)$$

Thus there will be n simultaneous equations of the above form, yielding the values of I in each of the $2n$ sections, symmetrically about the mid-point.

Equation (24) can be expressed in the form

$$I_\nu(\Phi_0 + \Phi_{2n-\nu+1}) + \sum_{\mu=1}^{n}(\Phi_{\nu-\mu} + \Phi_{2n+1-\nu-\mu})I_\mu + m_\nu i = 0 \quad . \quad (25)$$

These equations were solved for a coil (radius 3·06 cm., length 13·85 cm.) enclosed in a screen of radius 5·08 cm. and length 22·4 cm. The screen was regarded as being divided into 14 sections each 1·6 cm. long. For this coil and screen the values of Φ and m shown in Table 4 were found.

Table 4

Φ_0 17·31	Φ_1 8·87	Φ_2 4·61	Φ_3 2·79	Φ_4 1·78	Φ_5 1·21	Φ_6 0·84	Φ_7 0·60	Φ_8 0·44	Φ_9 0·33	Φ_{10} 0·26	Φ_{11} 0·20	Φ_{12} 0·16	Φ_{13} 0·13
m_1 104·05	m_2 163·76	m_3 248·28	m_4 337·06	m_5 402·51	m_6 440·59	m_7 456·90							

By inserting these values in equation (25), seven symmetrical simultaneous equations were obtained, which on solution yielded a distribution curve the shape of which is shown in Fig. 14. The maximum line current-density, represented by 1·0 in Fig. 14, was 5·54 amp. per cm. for a current of 1 amp. in the coil.

As a check, the inductance of the coil inside the tube was calculated

$$\left(\Delta L = \frac{2}{i}\sum_{\nu=1}^{n} M_\nu I_\nu\right)$$

and was found to be within 4 % of the measured change.

(2) Equivalent Flat Band

If g/l is small the curvature of the screen cannot be important and the shape of the distribution curve will differ little from that appropriate to a flat band of width l distant g from an infinite plane (see Fig. 2).

If P is a point on the plane, distant x_1 from one end of the band of wires, and x_2 from the other end, then at P

$$\frac{H}{i} = 4\int_{x_1}^{x_2} \frac{gU}{(x^2 + g^2)}dx$$

$$= 4U\left(\arc\tan\frac{x_2}{g} - \arc\tan\frac{x_1}{g}\right)$$

$$\therefore \quad \sigma = \frac{H}{4\pi} = \frac{iU}{\pi}\left(\arc\tan\frac{x_2}{g} - \arc\tan\frac{x_1}{g}\right)$$

For the coil considered in Section (1) above,

$$l = x_2 - x_1 = 13\cdot85 \text{ cm.,}$$

and $\quad g = 2\cdot02$ cm.,

and we obtain the results shown in Table 5.

Table 5

$\frac{x_1 + x_2}{2}$	0	2	4	6	8
$\frac{\sigma}{\sigma_0}$	1·0	0·98	0·912	0·715	0·368

This curve is also shown in Fig. 14.

The Figure indicates that the shape agrees well with the results of other methods; but the absolute magnitude obtained by this calculation is not correct. For the purpose of estimating screen loss, however, a simple and, when l/g is large, a close approximation is found by taking the maximum ordinate as that obtained from equation (1).

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* *Hochfrequenztechnik und Elektroakustik*, 1934, **43**, p. 76.

(3) Search Coil

Since the resistivity of the tube is not zero, the net rate of change of flux threading any cross-section is not zero but is equal to the current density multiplied by $2\pi a\rho m$. Such net rate of change of flux can be measured by the voltage induced in a narrow search coil placed just inside the screen (or, for that matter, outside it), and the curve relating this voltage with the axial co-ordinate of the search coil will be proportional to the distribution curve of the current induced in the screen. A distribution curve obtained from such a search-coil test on the same coil and screen as those considered in Sections (1) and (2) above is included in Fig. 14.

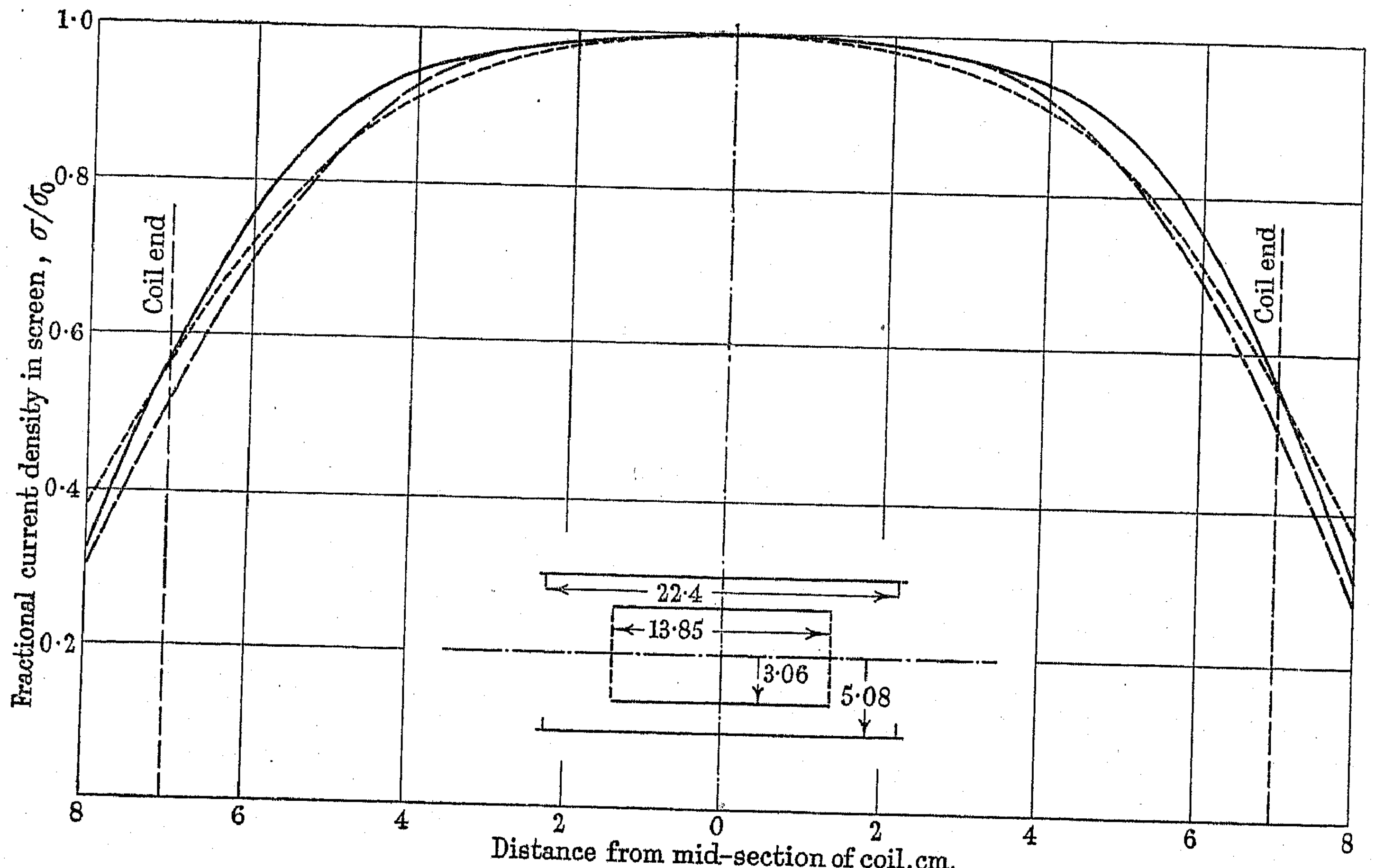

Fig. 14.—Axial distribution of currents induced in screen tube: arrangement of coil and screen inset.

Broken-line curve: calculated by sub-division method. Dotted-line curve: calculated for equivalent flat band. Full-line curve: obtained by search-coil measurements.

Experiment shows that the magnitude of the induced voltage is very sensitive to the radius of the search coil, and indeed consideration will show that this must be so. Thus, consider Fig. 1: the magnetic field in the space between the coil and the tube is uniform and that within the coil is also uniform and oppositely directed. If the resistivity of the screen were zero, it follows from (1) that the voltage induced in a search coil of radius c would be given by

$$\frac{d\Phi}{dt} = 4\pi^2 I(a^2 - c^2)\omega$$
$$\simeq 8\pi^2 Iag\omega,$$

where $a - c \equiv g$.

When the resistivity of the screen is not ignored, it follows, after reduction from (3), that

$$\frac{d\Phi}{dt} = 4\pi^2 Ia\left(1 + \frac{16\pi^2 g^2 f}{\rho}\right)\sqrt{(\rho f)}$$

The term involving g is approximately equal to unity when $f = 10^2$ kc./s., unless g is less than 0·1 mm. Hence it follows that the voltage induced in a search coil will depend much more on g than on ρ: if the absolute value of I were to be deduced from the voltage reading, then the search-coil diameter would need to be less than the diameter by an amount sufficient to allow g to be measured accurately.

Measurements were attempted with an external search coil, but were disturbed by capacitive effects too troublesome to eliminate.

Thus search-coil measurements may be used to show the shape of the distribution curve of the current in the screen, but it is impracticable to determine from them the absolute value of the mid-ordinate; though in fact this maximum ordinate will not differ very much from the limiting value given by equation (1) if l/g is greater than about 3. However, when the mutual inductances between the coil and sections of the tube are known, as in Section (1) above, the value of the maximum ordinate can be calculated to a close approximation once the shape of the distribution curve has been found. It is possible to calculate an expression for the inductance of a coil when influenced by a screen-current distribution of known shape and unknown size; since the effective inductance is known [by measurement, or from equation (12)], the requisite magnitude of the screen current can be deduced.

When the search-coil readings have been thus adjusted, the maximum ordinate is found to be 5·61 amp. per cm., which agrees very well with the value 5·60 amp. per cm. derived from equation (1) and the value 5·54 amp. per cm. obtained from the method of sub-division for the same coil and screen.

It is interesting to compare the values of R' obtained by the various methods:—

From the sub-division method, $R' = 4\,970\sqrt{f}$ microhms;
From the equivalent band, taking the maximum ordinate as the current density given by equation (1), $R' = 5\,130\sqrt{f}$ microhms;
From adjusted search-coil readings, $R' = 5\,320\sqrt{f}$ microhms;
From equation (19), $R' = 5\,030\sqrt{f}$ microhms.

From Fig. 14 it is obvious that practically all the I^2R loss in the screen is due to currents circulating within a length of screen equal to the length of the coil. So this length l is the only portion of the screen tube which need be made of highly conductive material for the screen losses to be as low as possible. Thus if a screening container of normal size were constructed of a less conductive and cheaper material, and in it were incorporated a sleeve of copper of length l, the cost of the material used would be considerably reduced, without sensibly impairing either the efficiency of the screening or the quality of the coil. However, the reduction of the overall cost of a screen, as distinct from the material cost, would probably be noticeable only where a large number of screens was concerned, as, for instance, in the mass production of wireless sets.

PART 5

CONCLUSION

It has been found that the effect of a screening tube on the inductance of a coil at radio frequencies is sensibly independent of the frequency and the resistivity of the screen material. For a coil of finite length l, a length l_t of tube causes as much change of inductance, and so gives as complete screening, as an infinite length, where l_t is determined by

$$\left(\frac{l_t}{l} - 1\right)\left(\frac{l}{b} - 0{\cdot}38\right) = \frac{a}{b} - 0{\cdot}84 \quad . \quad . \quad (11)$$

When the length of the tube is greater than or equal to the value given by (11), the decrease ΔL in inductance of the coil is given, within 2 %, by

$$\frac{\Delta L}{L} = \frac{l/g}{(l/g) + 1{\cdot}55}\,\frac{b^2}{a^2} \quad . \quad . \quad . \quad (12)$$

Furthermore, this formula is equally applicable to a totally enclosed coil, provided that the length of the tube is greater than or equal to $(l + 2g)$, g being the radial gap between the coil and the screen.

As should be expected, a small eccentricity of the coil inside the screen has only a second-order effect on the coil inductance, and such small changes may be estimated from

$$\frac{\delta L}{L_2} = 0{\cdot}535\frac{\epsilon^2}{g^2}\,\frac{g}{l+g}\,\frac{a}{b}\,\frac{L_1 - L_2}{L_2} \quad . \quad . \quad (13)$$

With the aid of this formula and others it is possible to estimate also the effect of the screen on the temperature coefficient of inductance, and it has been shown that the presence of the screen is likely to make the temperature coefficient less than for an unscreened coil, or even possibly negative.

It is seen that, at radio frequencies, screens of the materials customarily used may be regarded as infinitely thick. The eddy currents are concentrated near the inner surface, at a depth small compared with the radius of curvature, and so the problem of screen resistance becomes that of a flat, infinitely thick plate, whose radio-frequency resistance is easily found. Since the inductance change, and hence the eddy-current distribution, has been shown to be sensibly independent of the frequency and the resistivity, a resistance formula closely linked with (12) is to be expected.

The formula

$$R' = \frac{\Delta L}{L}\left(\frac{Ub}{a}\right)^2 \times 2\pi a p m l \text{ per unit length of coil} \quad . \quad (19)$$

gives a sufficiently correct value for the increase of effective coil resistance due to the presence of the screen. It must be noted, however, that this increment takes account of the resistive losses in the screen only, and neglects the decrease of dielectric loss indirectly caused by screening the coil.

ACKNOWLEDGMENTS

The experimental work described in this paper was carried out in the Engineering Laboratory, University of Oxford, under the direction of Dr. E. B. Moullin. The author is indebted to Dr. Moullin for advice with the measurements and for help in preparing the manuscript.

APPENDIX

Note on the Equivalent Flat Band

In Part 1, Section (3), an approximate estimate of the inductance of a screened coil was made, by regarding the coil as a single flat band of wires placed opposite a conducting plane (see Fig. 2). A better approximation can be reached by regarding the screened coil as a pair of parallel bands of wire, distant $2b$ apart, placed symmetrically between two infinite conducting planes, distant $2a$ apart; from this we can assess the order of approximation obtained from the single flat band.

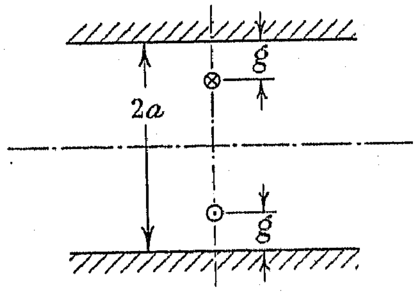

Fig. 15.—Two parallel wires placed symmetrically between two parallel conducting planes.

It is obvious that when the breadth of the band l is large compared with a, this approach will yield results approximating very closely to the results of equation (1): the case of practical interest is that of the short coil. However, the exact evaluation for a pair of bands of finite width is difficult, and it is convenient and reasonable to take the extreme case, that of a pair of wires, for which an exact evaluation is readily found.

Fig. 15 shows the arrangement corresponding to a single turn of wire inside a cylinder. The radius r of the wire may not be neglected, because the magnetic field would then be found to be infinite at the centre of the wire.

From the well-known expression for the vector potential of a system of images* we can derive an expression† for the vector potential A at any point between the planes:

$$\frac{A}{i} = \log\left(\cosh\frac{\pi x}{2a} + \sin\pi\frac{y+g}{2a}\right) + \log\left(\cosh\frac{\pi x}{2a} - \sin\pi\frac{y+g}{2a}\right) - \log\left(\cosh\frac{\pi x}{2a} + \sin\pi\frac{y-g}{2a}\right) - \log\left(\cosh\frac{\pi x}{2a} - \sin\pi\frac{y-g}{2a}\right)$$

Then, for the vector potential at the inner surface of the wire, we have $x = 0$, $y = a - g - r$, $y + g = a - r$, $y - g \simeq a - 2g$; and the expression simplifies to

$$\frac{A}{2i} = \log\frac{\pi r}{2a} - \log\sin\frac{\pi g}{a} \quad . \quad . \quad . \quad (26)$$

Now $g < a$, and in practice g is usually less than $a/2$, so that we may approximate:

$$\frac{A}{2i} \simeq \log\frac{\pi r}{2a} - \log\frac{\pi g}{a}\left(1 - \frac{\pi^2 g^2}{6a^2}\right)$$

$$\simeq \log\frac{r}{2g} + \frac{\pi^2 g^2}{6a^2}$$

or

$$-\frac{A}{2i} = \log\frac{2g}{r} - \frac{\pi^2 g^2}{6a^2} \quad . \quad . \quad . \quad . \quad . \quad (27)$$

$$\text{Screened inductance of coil} = \frac{2A}{i}$$

$$= 4\log\frac{2g}{r} - \frac{2\pi^2 g^2}{3a^2} \quad . \quad (28)$$

The inductance found by regarding the coil as two single-wire systems [Part 1, Section (3)] would be $4\log(2g/r)$, so that if $g << a$ the difference is very small.

It is interesting to calculate the error introduced when $g/a = 0\cdot 5$ (the largest value of g/a which is likely to occur in practice):

From (26),

$$\text{Screened inductance} = 4\log\frac{2a}{\pi r}$$

For two single-wire systems,

$$\text{Screened inductance} = 4\log\frac{2g}{r} = 4\log\frac{a}{r}$$

$$\text{Difference} = \log\frac{\pi}{2}$$

which must be a very small proportion in any practical case.

Thus it appears that a negligibly small error is introduced by the initial assumption of Part 1, Section (3), for any value of g/a which is likely to occur in practice, whatever the length of the coil.

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* See B. Hague: "Electromagnetic Problems in Electrical Engineering"; and E. B. Moullin: "The Principles of Electromagnetism," p. 228.

† It can be shown from this expression that when a second coil is introduced into the tube the mutual inductance between the two varies with the distance apart in a manner which differs insensibly from an exponential variation, provided that the distance is not less than about $2a$. This result has been applied to the design of attenuators which have a linear decibel scale (see *Proceedings of the Institute of Radio Engineers*, 1935, **23**, p. 578).

CIVIL AIR TRANSPORT COMMUNICATION

By A. D. HODGSON, Member.*

(*Paper first received* 12*th July*, 1939, *and in revised form* 19*th March*, 1940; *read before the* WIRELESS SECTION 1*st May*, 1940.)

SUMMARY

Any form of transport calls for a communication and signalling system, and by its nature civil air transport has to rely on radio-telegraphy and radio-telephony for the majority of the services it requires, and is peculiarly dependent on navigational help by radio. As a result an extensive communication system has been built up to provide these services throughout the world, a system which is closely interconnected internationally and which provides a service for the aircraft of any country operating on the various routes.

It is proposed to give in this paper a description of the system in this country and its immediate connections to the Continental and Empire networks, with some reference to the American system as an indication of the general differences between American and European practice.

The paper is divided into the following Sections:—

(1) The growth of the communication system.
(2) Technical considerations and requirements of ground-station equipment.
(3) Aircraft radio equipment and installation.
(4) The Atlantic and Empire routes to the East.
(5) A brief outline of the communication system in the U.S.A.
(6) Future developments.

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(1) THE GROWTH OF THE COMMUNICATION SYSTEM

Few people in the early days would have visualized the growth of civil aviation into a first-class transport system, and at that time the development of radio-communication by continuous-wave telegraphy and telephony was only just beginning.

Thus the early civil aviation communication system was relatively simple in comparison with the present complex network. Nevertheless, it gave the best service it could to the London–Continental routes.

Flying was mainly a fair-weather business, i.e. night services and operation in fog and bad visibility were not, as a rule, deliberately attempted.

Communication with aircraft was somewhat difficult; telephony was used and the aircraft equipment was operated by the pilot by means of remote controls. The receivers were relatively insensitive, and transmitter frequency was more or less uncontrolled and liable to change from time to time. Ignition interference was also very troublesome. Acoustic noise added to the difficulties. However, the developments taking place in radio equipment and organization removed these early difficulties and facilitated flying under adverse weather conditions, and, as a result of the appreciation of the great value of the radio system and organization as a primary aid to air transport, a considerable expansion in the radio services became necessary.

Not only did there arise a need for the expansion of services for given routes, such as the London–Continental route, but the need for the development of air routes and services within the country necessitated an extensive communication system, without which a regular and co-ordinated aerial transport system could not be planned and organized.

Communication Requirements

The communication requirements can be divided into categories of messages, as follows:—

A. Ground to air, and vice versa.

(1) Direction-finding and navigation assistance in the form of requests from the aircraft for true or magnetic reciprocal bearings, etc., actual fix or position by triangulation, etc.

(2) Emergency, distress, etc. Actual distress calls in the event of forced landing, particularly over sea, or emergency calls for urgent navigational assistance.

(3) Meteorological and weather information in the form of regular broadcasts of weather reports or demands for actual weather, warnings of deterioration, fog, line squalls, etc.

(4) Messages reporting changes of height, flying in, below, or above cloud, etc.

(5) Position reports.

(6) Landing assistance by beacons or other means.

B. To and from airports.

(1) Departure message, i.e. a message sent from one airport to the next port of call and/or the terminal airport to which an aircraft is proceeding, giving the time of departure, the pilot's name and details of load.

(2) Arrival messages giving the time of arrival of the aircraft to the port of departure and/or the last port of call, etc.

(3) Booking and reservation messages.

(4) Companies' service messages, such as requests for spares, alterations of schedules, etc.

(5) Meteorological and weather reports of fog and application of fog regulations.

(6) Navigational warnings concerning, for example, the state of an airport during heavy rain, obstructions, alterations, etc.

(7) Aircraft movements.

(8) Administrative messages.

Meteorological Services

In addition to these categories of messages there is a separate collection and dissemination of meteorological information in the form of broadcasts in code, from

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* Air Ministry.

various points, of regional or synoptic reports. These are passed to the appropriate meteorological offices for the preparation of forecasts, weather maps, etc.

The Stations in Operation

In 1932, Croydon, Pulham and Lympne were the first main stations and served the London–Continental routes in conjunction with Le Bourget, Brussels, Ostend, St. Inglevert and Amsterdam. Interest in regular internal routes began to be active in about 1933, during which year a new radio station was opened at Manchester Airport. Development of internal routes necessitated the erection of stations at various airports throughout the country. At first neither the routes to be served nor the actual airports to be used were definitely settled, and therefore to meet the contingency of a change of airport the additional stations required were provided in the form of mobile trailers fitted with transmitters and direction-finding receivers and provided with Douglas-engine-driven generators as a standby for power supply failure. The transmitters were relatively simple and were not provided with master oscillator circuits.

Table 1

	Dec. 1932	Aug. 1933	Nov. 1933	Dec. 1935	Aug. 1935	Nov. 1935	Jan. 1938	Mar. 1938	June 1938	Dec. 1938
True bearings	100	275	520	950	1 200	1 300	900	475	250	550
Magnetic reciprocals	200	60	650	1 100	900	2 150	2 300	900	350	1 400
Position fixes	100	30	125	150	100	200	Very few	Very few	—	—
Weather	375	500	650	850	1 150	1 000	2 000	2 100	2 200	1 950
Number of aircraft communicated with by telegraphy ..	450	975	500	1 150	2 950	1 700	1 900	2 450	3 650	1 700
Number of aircraft communicated with by telephony ..	150	500	200	nil	240	50	nil	50	200	30

Working on this basis, the following radio stations were in operation in 1934:—Croydon, Lympne, Pulham, Manchester, Renfrew, Hull, Newtownards and Portsmouth.

Apart from navigational assistance the most important function of the communication system is that of enabling the movements of aircraft to be controlled. According to the results of direction-finding bearings, track, speed and time of departure, it may be necessary to issue instructions with regard to height of flight, etc. The inter-airport channels are, therefore, as much concerned with safety of the aircraft as the ground-to-air channels, and it is necessary to organize the message-handling arrangements so that messages of departure time and route are passed as rapidly as possible. Speed on all channels is of paramount importance, and of course priority arrangements are made for certain classes of messages.

In order to give some idea of the trend of traffic, the number of aircraft messages passed in telegraphy and in telephony are given in Table 1 for the years 1932–33, 1935–36 and 1938–39 at Croydon.

It is of interest to note the decrease in navigational assistance by position fix, due principally to the decrease of accuracy with increase of aircraft speed.

At Croydon alone the number of aircraft handled has increased from 600 to 1 730 per month in 6 years, and roughly the same increase has taken place elsewhere. Between, for example, Heston and Croydon and the Continental airports there will be 2 500/3 000 aircraft movements per month in the triangular area with Heston at the apex and Clacton and Brighton at the base angles.

The problems to be faced are those of increasing aircraft and communication traffic, increasing speeds of aircraft, the need to reduce the time taken in approach and landing in bad visibility, and greater attention to prevention of collision. From the point of view of a traffic-handling organization there is of course no comparison with a commercial point-to-point channel, but the stress can be visualized by considering the following time-table of arrivals and departures to and from Croydon on the 29th July, 1938.

Time (G.M.T.)	Arrival	Departure
00.00–05.00	1	2
05.00–10.00	5	20
10.00–12.00	2	10
12.00–15.00	21	14
15.00–18.00	15	15
18.00–21.00	15	16
21.00–24.00	9	1
	—	—
Totals ..	68	78

Between 12.00 and 15.00, communications concerning 35 aircraft would have had to be handled, and if the weather had deteriorated severe congestion would have been likely to result. A reserve capacity has to be allowed for peak loads due to weather conditions—a difficult matter to arrange economically. Too many channels and changes of frequency in themselves tend to increase the amount of communication necessary to operate the route and to render interception by co-operating stations difficult.

The Aeronautical Frequency Band

The erection of additional stations and the increase of traffic soon began to cause difficulties by the crowding of the services required into the very limited frequency band allocated to aeronautical services at the International Telecommunication Conference in Madrid. The difficulties are accentuated by the greater field strength required at the aircraft receiver in comparison with the ground receiver, the power required at the ground station resulting in a large interference signal in adjacent areas. Frequencies are, of course, staggered a few kilocycles, but the ground receivers cannot be worked at too high a degree of selectivity owing to the danger of missing calls from aircraft slightly off frequency, remembering that the aircraft transmitters are not crystal-controlled.

These frequency bands were 255–290 kc./s. for meteorological and point-to-point (inter-airport), and 320–365 kc./s. for ground-to-air and vice versa.

At a conference in Paris in November, 1933, the frequency band was arranged as follows:—

kc./s	
257	Beacons and point-to point
260	Point-to-point
264	
268	
276	Meteorological services
280	
284	
288	
325	Aircraft (D.F.)
330	Ground stations
333	General calling wave for aircraft
336	Ground stations
346	Aircraft
350	
350	Aircraft (aeronautical radio beacons)
363	

Under the Cairo Conference, additional frequencies above 363 kc./s. have been obtained for aeronautical services, while the band 257–268 kc./s. has been given to beacons and meteorological transmissions.

To release radio-frequency channels a teleprinter system was introduced to handle inter-airport traffic, with high-frequency channels for those routes which could not at first be conveniently connected by land-line. Inter-airport traffic was therefore removed from the band 255–290 kc./s. and these frequencies were allocated to the additional meteorological services which became necessary and also to omni-directional beacons, the latter with a view to reducing the amount of navigational traffic by encouraging air lines to make use of homing devices or loop direction-finders carried on the aircraft. At Croydon a double-channel D.F. system was put into service on 333 kc./s., both channels operating on the same frequency and so used that one operator employed his D.F. characteristics to eliminate interference and so assist in handling traffic, while the second operator independently took bearings on all calls made, thus being able to supply answers to requests for bearings with the minimum of delay and communication and at the same time keeping a check on the track of all aircraft.

Addition of Frequencies Obtained at the Cairo Conference

The pressure, however, still increased and further additions to routes and stations and the expansion on the Continent gave no time for a pause in the fight to improve the conditions, with the result that further demands for additional frequencies had to be made at the Cairo Conference in January, 1938. The result of this Conference was a re-allocation of frequencies for aviation communication in the medium-, intermediate- and high-frequency bands. Additional frequency bands were also provided in the ultra-high-frequency region for landing-assistance systems. The complete schedule can be found in the International Radio Communication Regulations (Cairo, 1938).

The Complete Communication System

In January, 1937, the " Committee appointed to Consider the Development of Civil Aviation " published its report and as a result it was decided to consolidate the communication system, to extend the facilities provided and to provide permanent stations in place of the mobile equipments originally used. The extended facilities were to include aids for landing in bad visibility, omni-directional beacons, Adcock direction-finding stations, etc. This work is now in progress, and in Fig. 1 the communication system as in operation in the summer of 1939 is shown.

With the growth of the routes, both internal and international, it became necessary to delineate areas over which aircraft would be under the control of a given station. In the early stages one station only, the area station, was in general provided in each area, but as other airports came into use in a given area so local control or zone stations had to be provided. Furthermore, such channels had to be provided at area stations in order to separate rapid short-distance navigational traffic from area traffic, i.e. in bad weather a local control zone is established into which aircraft are allowed one at a time and given individual attention on a separate communication and direction-finding channel. Other aircraft await their turn on the area channels and outside the boundaries of the local zone.

Facilities Required at a Main Station

The complete facilities required at a main airport are:—

(1) One or more area channels.
(2) A local zone channel.
(3) An approach and landing channel (u.h.f.).
(4) An omni-directional beacon.
(5) Inter-airport communication channels.
(6) An alternative to No. (3) in the form of a ZZ landing channel.
(7) Meteorological broadcasts.
(8) Meteorological reception.
(9) Miscellaneous special services.

Speed of operation of these channels, and particularly the ground-to-air channels, is of vital importance, not only from the point of view of handling the amount of traffic but also from a consideration of the speeds of aircraft. As an example, on the local or zone channel at Croydon bearings have to be taken and passed back to the aircraft at the rate of 4 or 5 per minute, and thus very fast and very well co-ordinated operation is necessary not only by the operator on that particular channel but by the operators on the other channels who pass an aircraft over to the zone channel.

During such a process as this the area-channel operators have the waiting aircraft to deal with, and as these accumulate the demands on the service increase very rapidly and seconds are of importance.

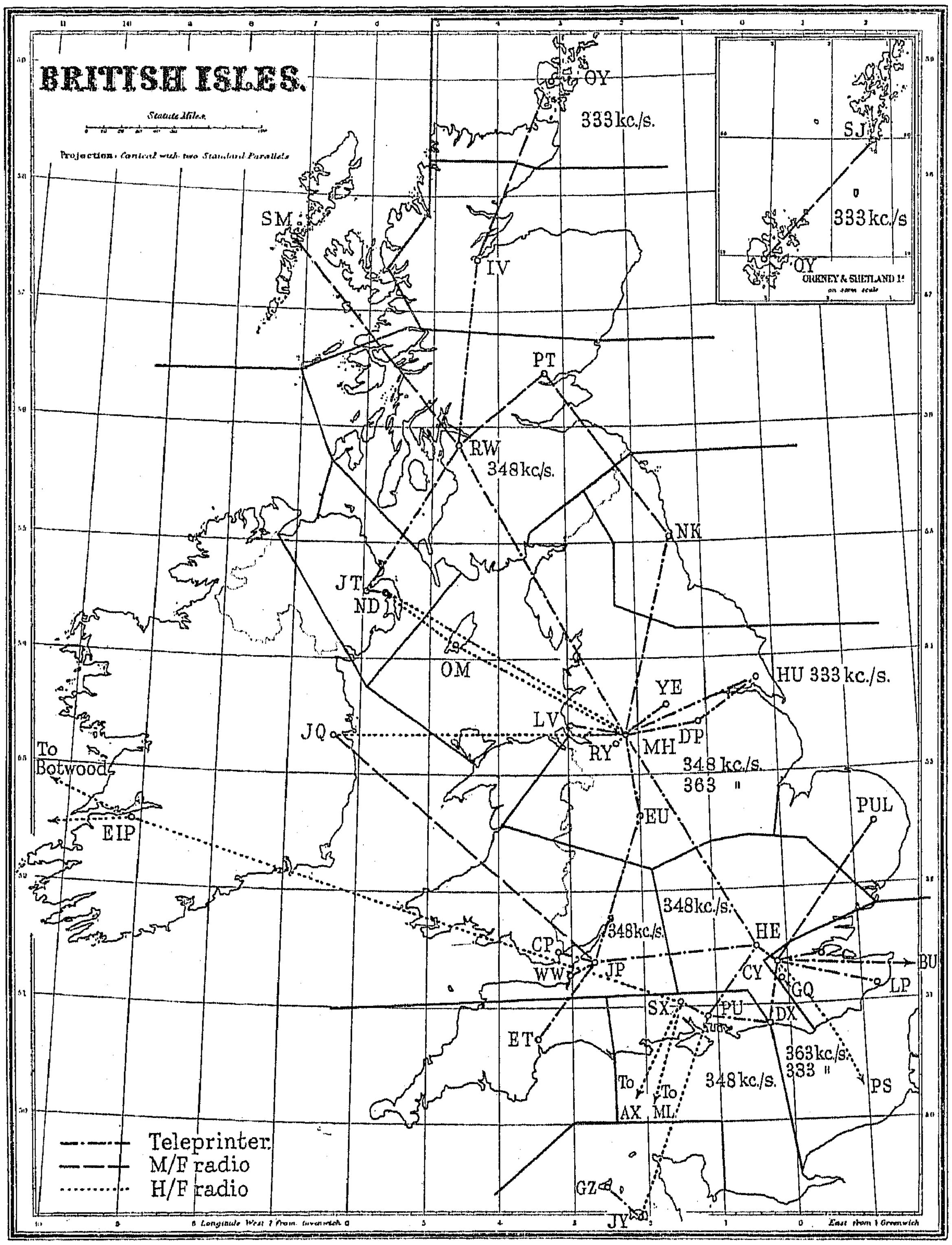

Fig. 1.—Communication areas and frequencies.

HU = Hull
DP = Doncaster
YE = Leeds
NK = Newcastle
RW = Renfrew
PT = Perth
IV = Inverness
OY = Kirkwall (Orkneys)
SJ = Sumburgh (Shetlands)
JY = Jersey
OM = Isle of Man
ND = Newtownards (Belfast)
CY = Croydon
HE = Heston
LP = Lympne
GQ = Gatwick
GU = Gravesend
DX = Shoreham
PU = Portsmouth
SX = Southampton
JP = Bristol
CP = Cardiff
WW = Weston-super-Mare
EIP = Foynes (Eire)
JQ = Dublin (Eire)
MH = Manchester
EU = Birmingham

To facilitate these rapid operations, and easy handling of traffic in general, the layout of the station is therefore of importance.

Planning and Layout of Stations

The criteria for the correct planning and layout of communication stations are:—

(1) Absence of fatigue and unnecessary movements.

(2) Accessibility of all equipment.

(3) Rapid change-over of items of equipment in the event of failure of any item.

(4) Easy passage of message slips, etc., to the required points.

(5) Avoidance of misplaced messages, lost messages, etc.
(6) Ease of logging and recording.
(7) Freedom of movement for staff.
(8) Ease of access to charts for laying-off bearings.
(9) Absence of noise and distraction.
(10) Freedom from electrical interference.
(11) Freedom from cross-modulation.
(12) Centralization, as far as possible, of the aeronautical and route traffic channels.

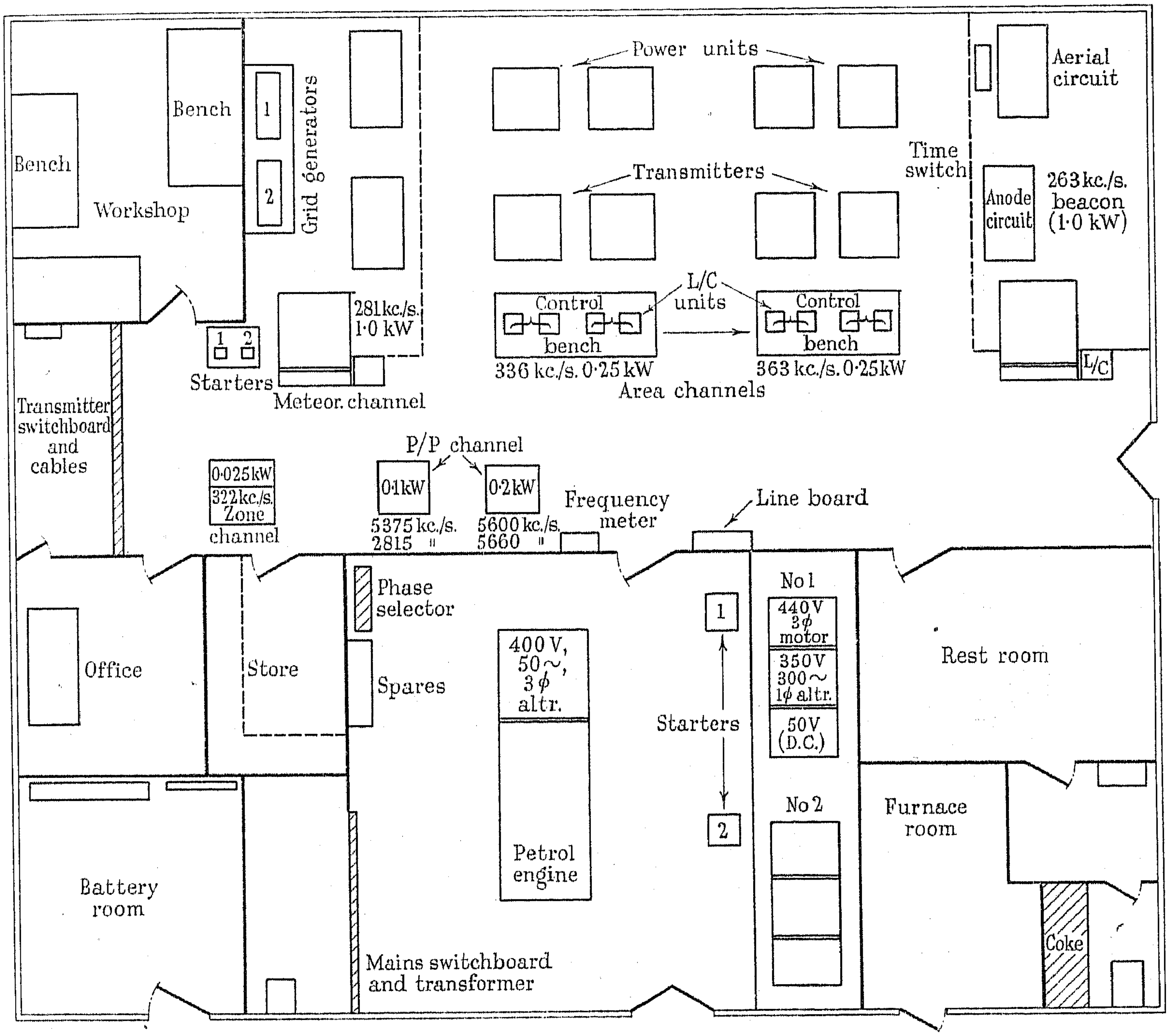

Fig. 2.—Layout of equipment in Mitcham transmitter station.

These requirements apply not only to the aeronautical channels but also to inter-airport, meteorological, etc.

Main Airport or Area Stations

In the first place, the layout of the station relative to the aerodrome must conform to certain requirements appertaining to obstruction, and thus the transmitting station and the Adcock D.F. site must be situated at a distance away from the aerodrome in order that the masts shall not constitute a hazard to flying; thus we find these points up to 3 miles from the airport.

Many of the stations now in use have grown up and expanded in existing airport buildings, and as a result accommodation has become congested as additional channels have become necessary.

Croydon, at which extensive alterations have taken place this year, is an example of a station at which the loop D.F. channels are on the airport as at the moment there is no site available for an Adcock station.

The transmitting station is situated on Mitcham Common, approximately 3 miles from the airport. This station houses the following equipment:—

(1) Main aeronautical channel transmitter on 336 kc./s.
(2) Standby.
(3) Second channel on 363 kc./s.
(4) Standby.
    (Both the working and standby transmitters also incorporate a high-frequency band, covering 5 660 and 2 850 kc./s.)
(5) Meteorological channel, 284 kc./s.
(6) Omni-directional beacon on 263 kc./s., complete with automatic clock control and code-sending mechanism.

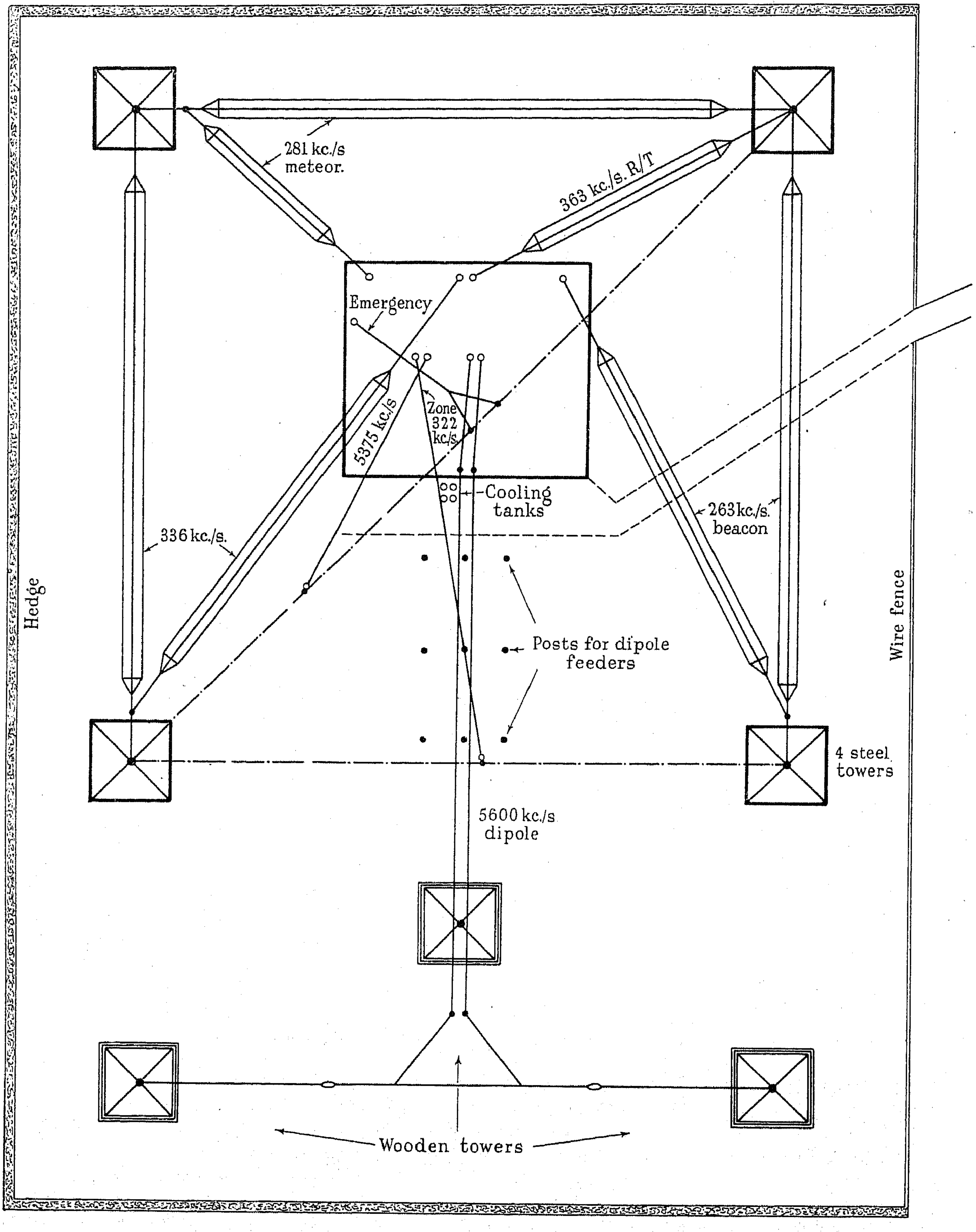

Fig. 3.—Mitcham transmitter station. Site and aerials.

(7) Standby for Nos. (5) and (6).
(8) Zone channel on 322 kc./s.
(9) Standby.
(10) Short-wave channel for inter-airport traffic on 5 600, 5 660 and 2 800 kc./s.
(11) Second short-wave channel covering 12 320 kc./s. and upwards for miscellaneous services.
(12) Power-supply equipment.
(13) Reserve power supply.

The layout of the equipment will be seen from Fig. 2.

Power supply is derived from 3-phase 400-volt 50-cycle a.c. mains and is distributed via a phase-selector board to the main power board. All transmitters except those enumerated at Nos. 5, 6 and 7 operate from a single-phase supply by means of rectifier systems, and thus the phase-selector board enables a quick change of phase to be made in the event of a phase failure.

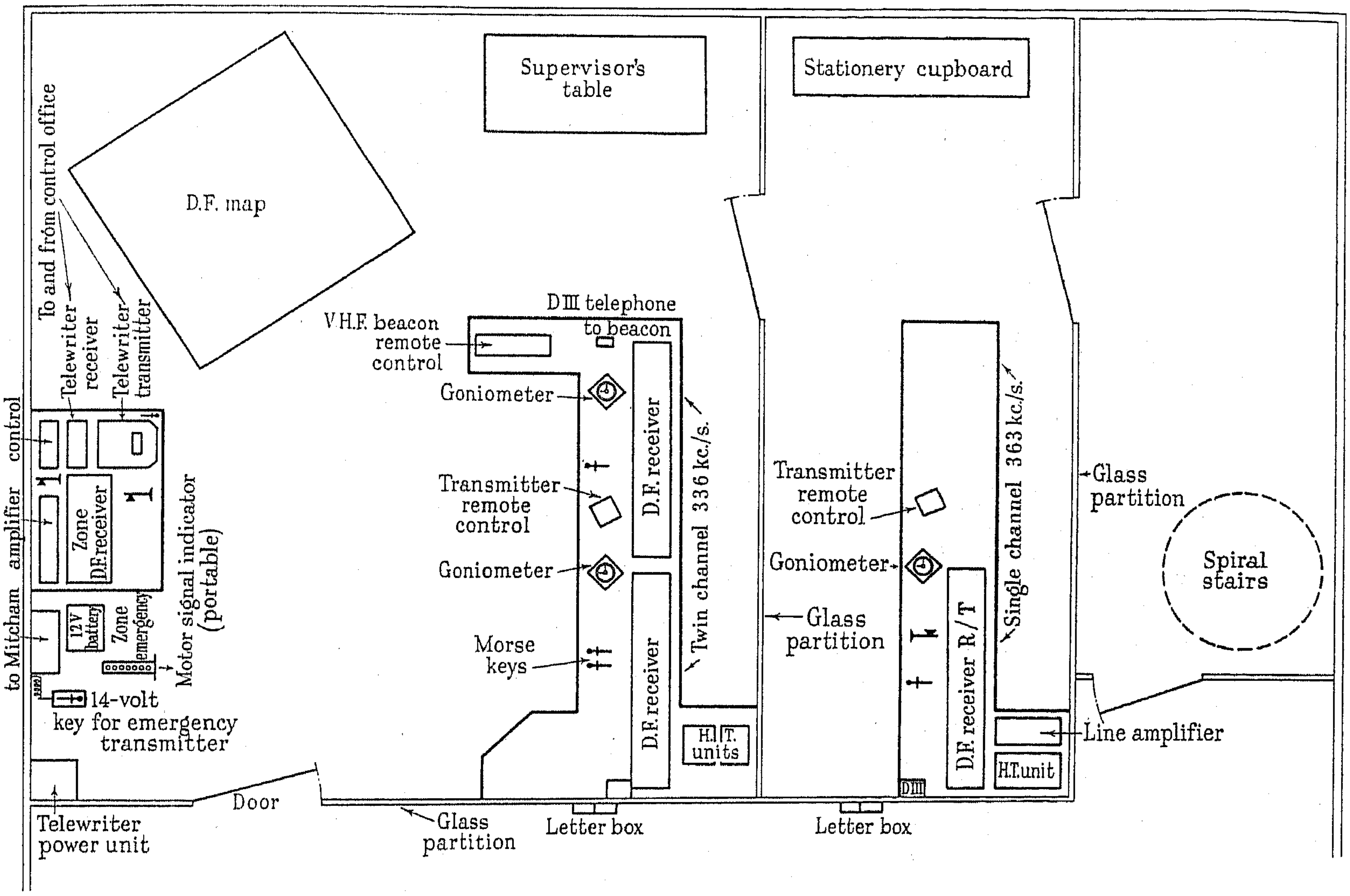

Fig. 4.—Layout of Croydon D.F. receiver station.

Transmitters Nos. 5, 6 and 7 require a secondary motor-alternator system which delivers 300-cycle single-phase power to the rectifier system and 50 volts (d.c.) for the operation of the grid-bias generator, remote controls, etc. These machines are, of course, in duplicate.

The reserve power plant consists of a 4-cylinder petrol engine driving a 30-kVA 50-cycle 400-volt 3-phase alternator. At newer stations a self-starting diesel emergency plant is being provided, and in due course such a plant may be added to Croydon.

The arrangement of the transmitter site and the aerial system can be seen from Fig, 3.

The aircraft reception and D.F. channels are, of course, housed in the control tower on the airport building in close proximity to the air-traffic control staff, and in Fig. 4 the layout is shown.

Next to the twin-channel D.F. receiver is situated the control unit for the u.h.f. approach beacon system, while behind the operators on the twin-channel receivers is situated the zone D.F. receiver. The control units for the transmitter, which employs an impulse-operated step-by-step system, can be seen next to the receivers. A line board for the remote-control lines enables the transmitters at Mitcham to be changed-over for operation from other points, viz. the 336-kc./s. transmitter can be operated from the 363-kc./s. receiver, and vice versa.

Message slips from the area channels are passed through hatches to the traffic control staff, but in the case of the zone channel, where a very high speed of operation is required, use is made of a telewriter by means of which the written bearings are instantly indicated to the traffic-control personnel who may be dealing with the approach of the single aircraft concerned.

In Fig. 5 are shown the inter-airport channels comprising teleprinters, high-frequency receivers and operating points, together with the meteorological reception and transmitter keying points. These do not require much explanation other than to indicate the pneumatic tube system by means of which messages are passed to the meteorological office, control tower, etc.

Immediately below the aeronautical channels is placed a battery room from which supplies are fed to those receivers which operate from this source. Although operation from the local a.c. mains is more or less general, the arrangements are such that batteries may be brought into use for emergency purposes in the event of mains failure, and for this reason also the teleprinter power supplies are fed from a separate cable direct from the main switchboard so as to reduce the risk of failure due to operation of fuses.

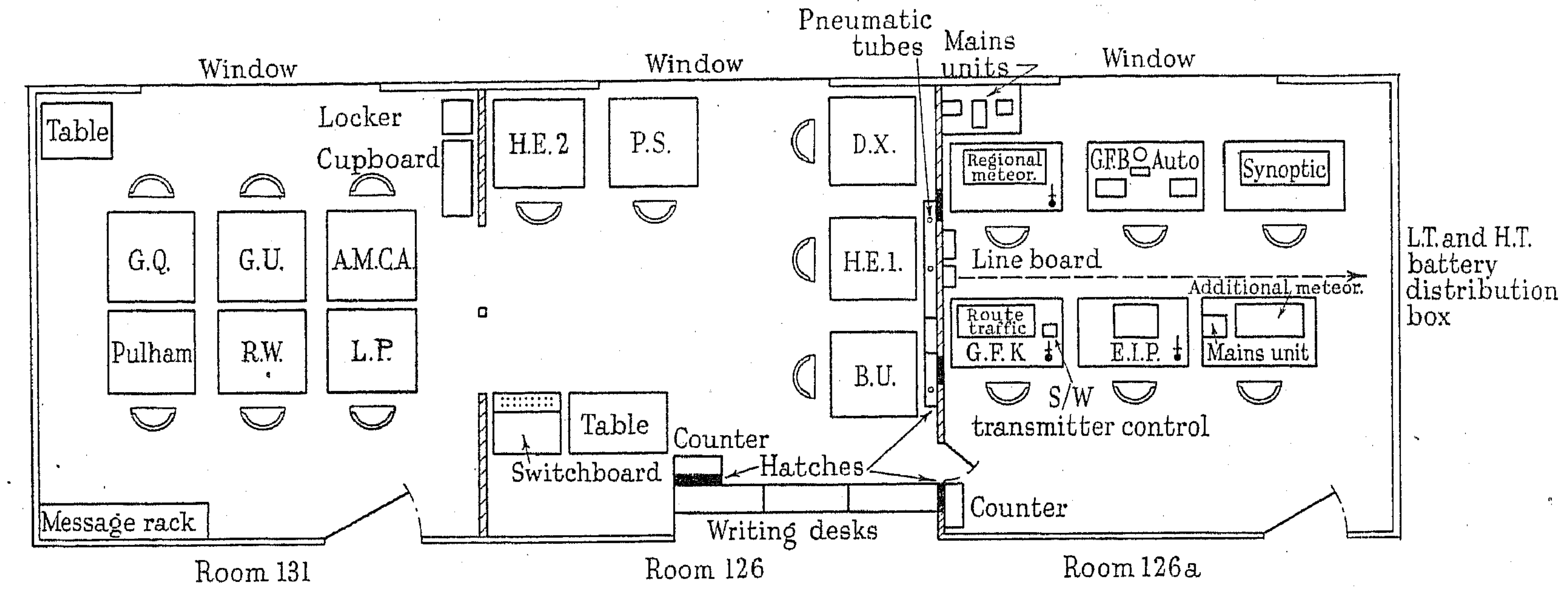

Fig. 5.—Layout of Croydon teleprinter station and point-to-point receiver station.

The D.F. aerial system at the airport is arranged on top of the control tower. The arrangement is not ideal, but it works.

When the opportunity occurs to consider the layout of radio accommodation during the early stages of the design of an airport building, careful consideration should be given by the architects to the requirements already mentioned and also such requirements as the provision of cable ducts, lead-in insulators, earth leads, bonding of the metallic structure of the building, etc. The necessity of long leads from D.F. loops should be avoided, and likewise the running of these leads close to other cables. Under these conditions an ideal layout can often be obtained in which zone and area channels are centralized with the overseer's office, teleprinter and meteorological accommodation, and provision made to allow for expansion and modification of services without disfiguring the building and making structural alterations.

At many of the new stations which are being erected to meet the proposal of the Maybury Committee this opportunity has occurred. At these stations the transmitter and Adcock D.F. stations are erected in separate buildings at distances of 3–4 miles from the airport. These buildings are, of course, planned to facilitate the layout of equipment. Examples are shown in Figs. 6 and 7.

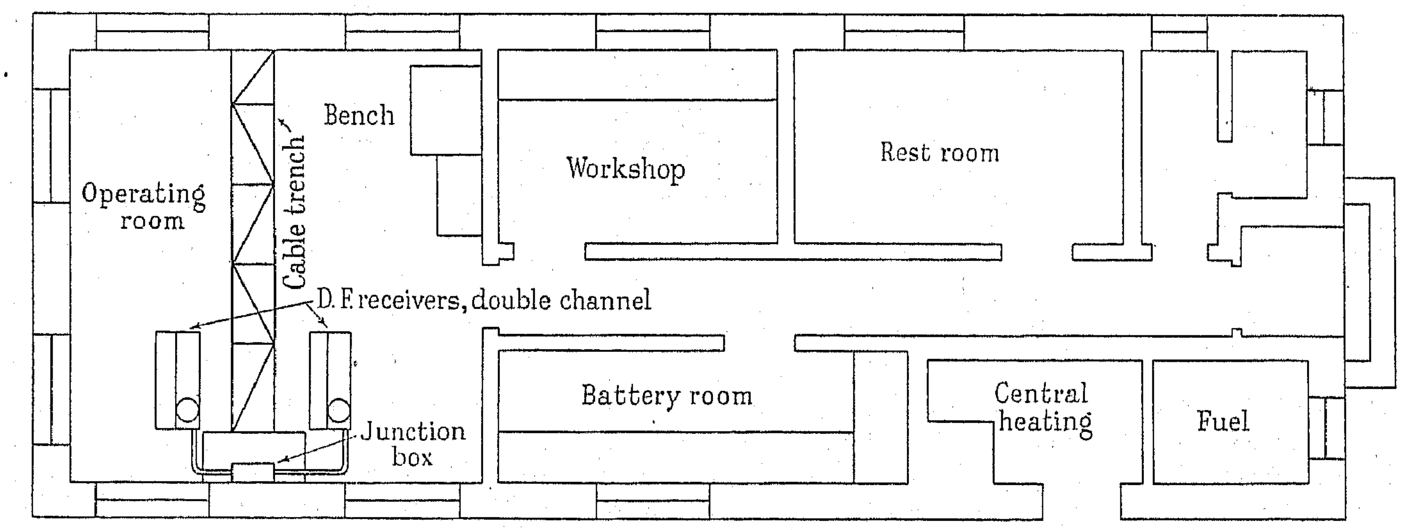

Fig. 6.—Plan of new area D.F. station (Adcock).

All other services are concentrated in the airport building. These comprise:—

(1) A D.F. receiver for area traffic and for interception of bearings passed by the Adcock station to aircraft.

(2) A D.F. receiver for use on the local zone channel.

(3) A u.h.f. beacon control system, the transmitters themselves being on the line of best approach to the airport.

(4) Meteorological reception and transmission (keying points).

(5) Teleprinter circuits.

(6) Short-wave point-to-point channels, reception and keying points.

In some cases the airport may also be provided with a ZZ D.F. channel situated on the line of best approach.

The fact that the main D.F. station is separated from the airport point necessitates a modification to the usual procedure. All bearings are taken and passed to the aircraft by the staff at the Adcock station, while the operator at the airport, by means of the separate D.F. receiver, intercepts the necessary details for the information of the air-traffic control personnel. Both the airport area operator, who handles all traffic other than D.F. bearings, and the Adcock D.F. operator, control the same transmitter by means of a change-over switch on the keying circuit. Intercommunication is also provided, and also the output from the D.F. receiver is passed by line to the airport operator, who can, if necessary, use these signals instead of his own receiver for communication purposes. Intercommunication is also provided between the zone and ZZ points and the transmitting station where all transmitters are located. It is to be understood that unless otherwise indicated all bearings are given from the Adcock D.F. station. When leading bearings to the airport on the area frequency are required from the airport D.F. channel a prefix is used to differentiate these bearings from those referring to the Adcock station only; usually leading bearings to the airport would be given on the local zone channel.

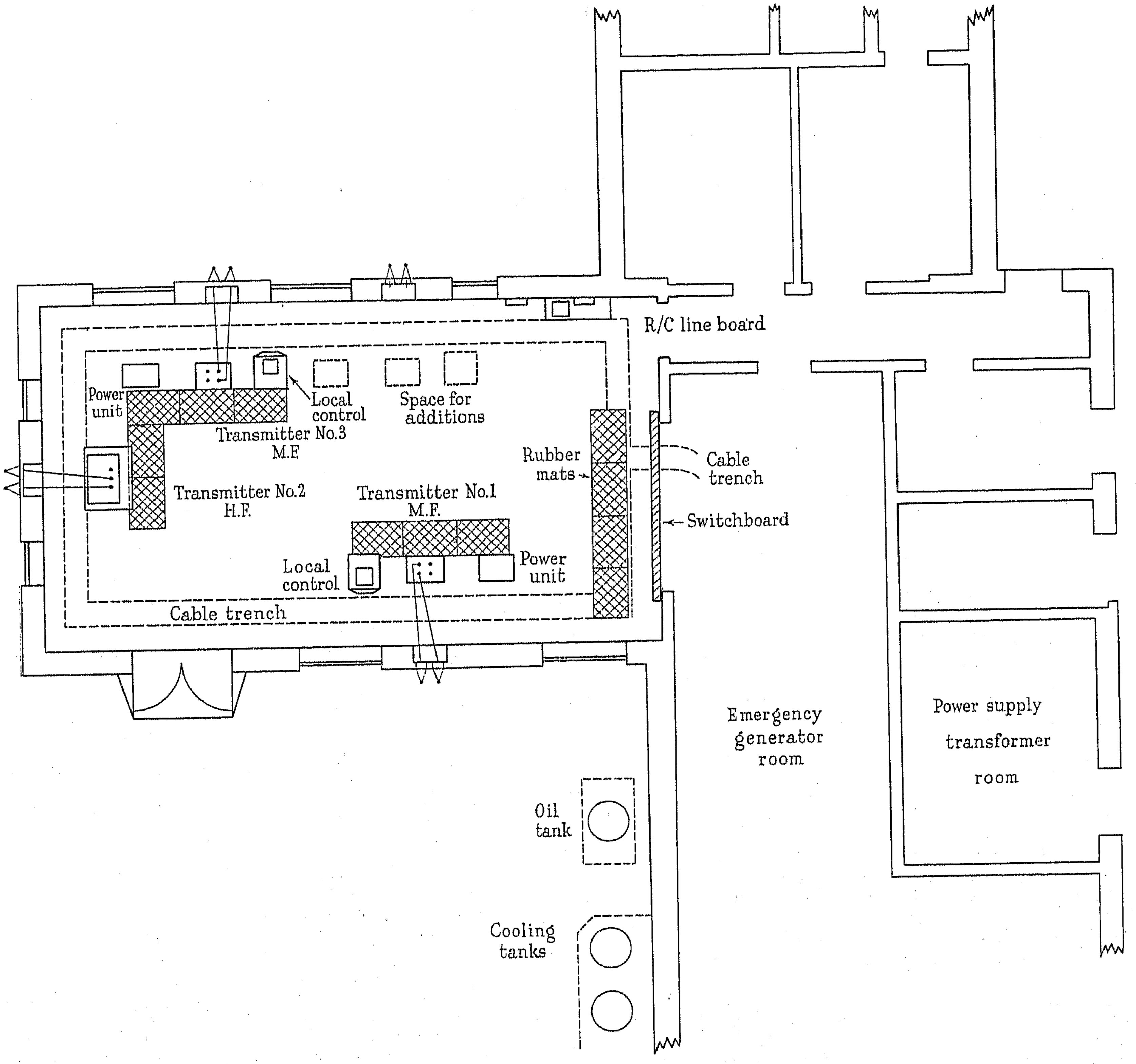

Fig. 7.—Plan of new area transmitter station.

In Fig. 8 is shown the layout of a typical up-to-date airport and area station incorporating all channels as planned in accordance with the communication requirements envisaged by the Maybury Committee.

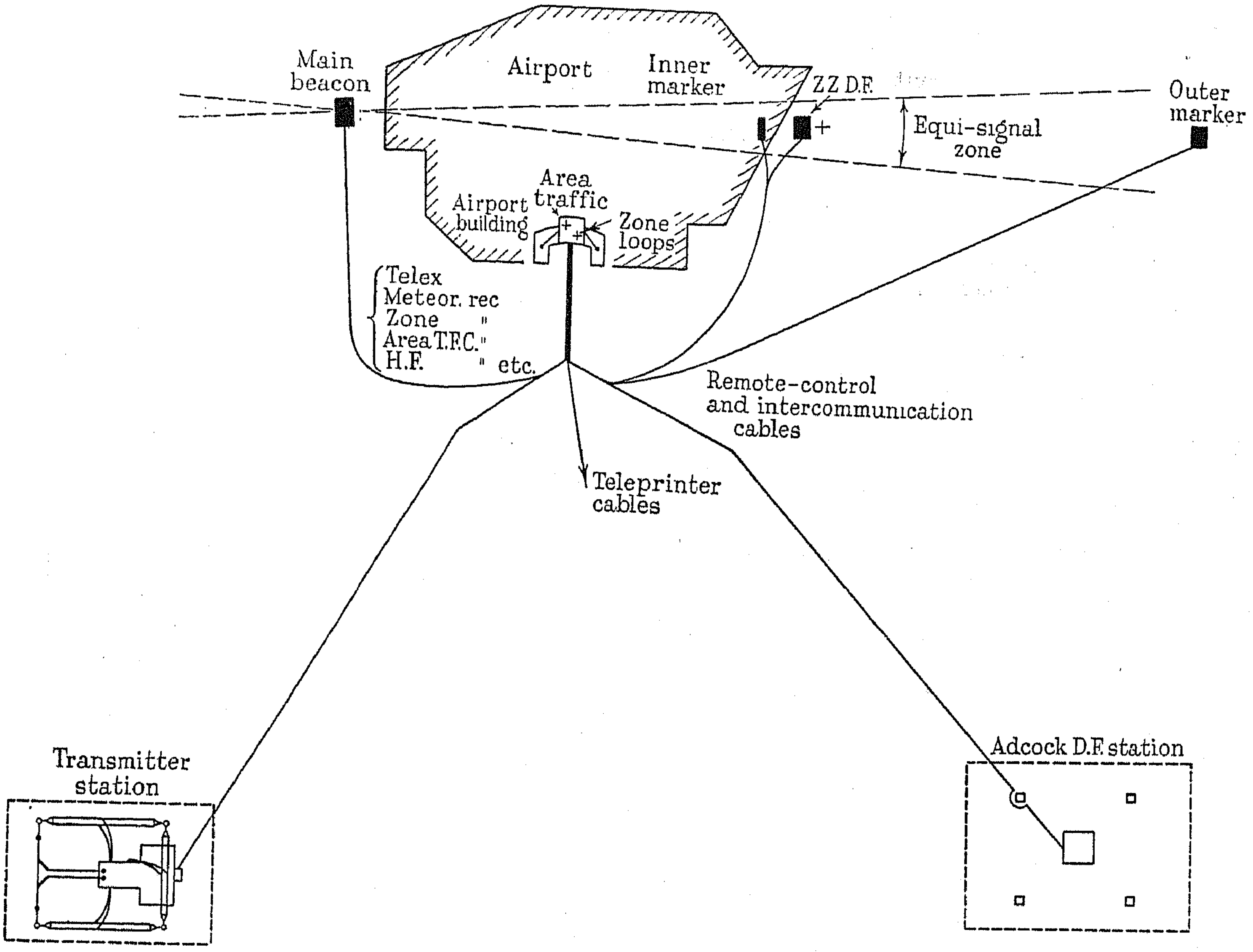

Fig. 8.—Layout of a typical airport station.

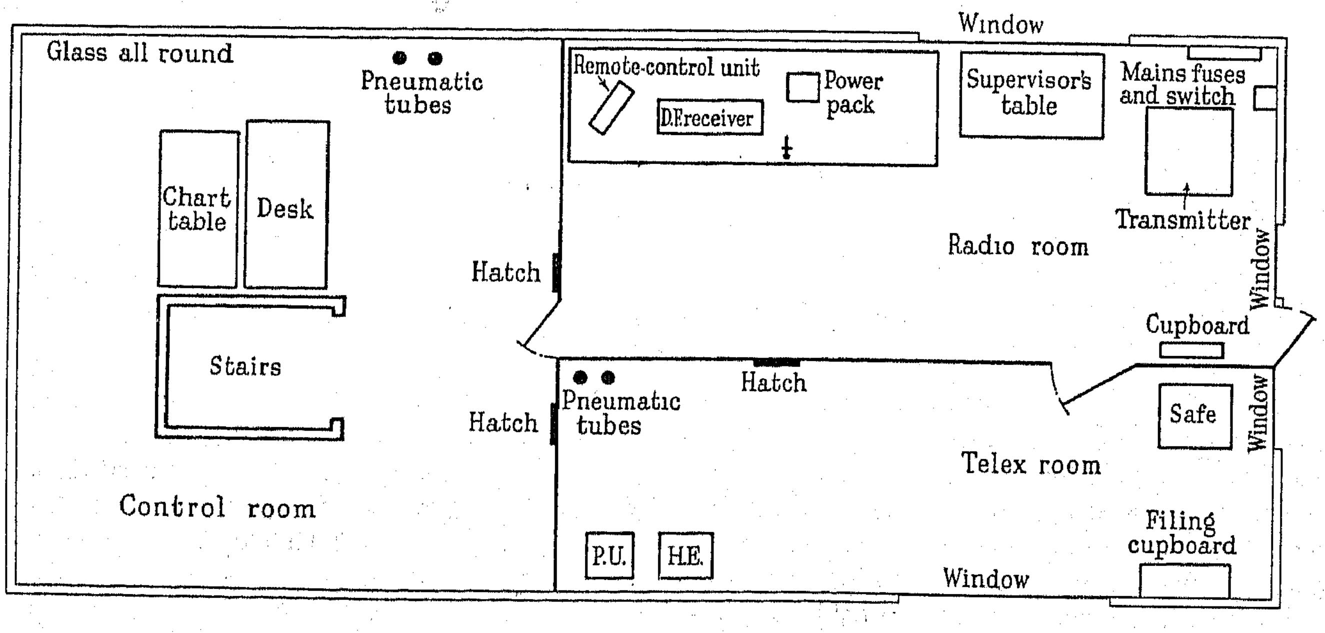

Fig. 9.—Layout of a subsidiary airport station.

Local Zone Stations

At a local zone station the problem of layout, etc., is very much simplified by virtue of the reduced services provided, and in general there is no separate transmitting and receiving station. The transmitter masts are quite low and in many cases no higher than the terminal building, to which they are often adjacent.

The layout is more centralized, and transmitter and receiver are in the same room. No remote controls are employed.

At such stations as these there are of course no meteorological or other channels, meteorological information being provided by teleprinter from the appropriate stations. Fig. 9 shows a typical layout.

(2) TECHNICAL CONSIDERATIONS AND REQUIREMENTS OF GROUND-STATION EQUIPMENT

At the commencement of civil aviation there were broadly two main systems of navigational assistance which could have been employed, viz. directional reception on the ground and directional transmission.

The former, utilizing medium frequencies, was employed, as this technique was more developed and had been employed in marine practice. The latter was developed in the U.S.A. in connection with the equi-signal beacon system, and is perhaps more applicable to the conditions of the air routes in U.S.A. where the distances involved are considerably greater than in Europe, and where the international aspect of communications does not have to be considered.

Difficulties have been experienced with deviations and splitting of the equi-signal path in mountainous country and with aircraft which have strayed from the equi-signal path and have been unable to return to it.

An equi-signal beacon has been tried at Croydon airport but was eventually discarded as being unsuitable for the conditions appertaining on the routes, and furthermore the narrow frequency band available for civil-aviation communication did not permit such beacons to be employed.

Direction-finding on board the aircraft itself was tried in the early days of civil aviation and is now being developed to a high degree of efficiency. An aircraft is, however, an unsuitable platform on which to take bearings, and this system, whilst a useful adjunct to a ground organization, could not entirely supersede it. It is just as important for the ground personnel as for the aircraft crew to know the location of the aircraft.

Perhaps the biggest advantage of the directional reception system is that the ground radio staff can at all times ascertain the position and track of the aircraft and give attention to the danger of collision and to the orderly movements of the aircraft, particularly during bad visibility. In the event of an emergency forced landing the position of the machine can be ascertained.

Direction-Finding Equipment

Navigational assistance on the internal and Continental routes has therefore developed on the lines of a main area D.F. station of Adcock type assisted by subsidiary and local zone D.F. receivers employing loop aerials.

The main area station situated, for example, at one of the new airports may have, as already shown, as many as five D.F. channels:—

(1) A double-channel Adcock D.F. equipment operating on two area frequencies.

(2) An airport area traffic channel employing loop aerials.

(3) An airport local zone channel for leading bearings employing loop aerials.

(4) A ZZ landing system employing loop aerials.

Table 2

Dimensions	Turns	Gain
		db.
19·5 ft. × 19·5 ft. × 22 ft.	1	− 0·7
	2	+ 6·6
	3	+ 9·8

Type of station	Signal strength for ± 1° accuracy at 333 kc./s. μV/m.
Adcock double-channel .. .. .. H = 100 ft. D = 200 ft.	2
Ditto single-channel and 1 800 ft. extended feeder cable	4
3-turn loop above	3·3
Adcock single-channel .. .. .. H = 75 ft. D = 130 ft.	3·2

Approximate Average D.F. Performance Swing for various Field Strengths.

Field strength	(1)	(2)	(3)
	Total swing	Total swing	Total swing
μV/m. 3	12°	9°	8°
5	9°	5°	4°
7	6°	3½°	2½°
9	5°	2½°	1½°
15	3½°	1½°	1°
20	2½°	1°	1°

(1) Screened-loop aerials, 4 ft. diameter

(2) Open-loop aerials, 1 turn, 17 ft. × 18 ft.

(3) Adcock, 100 ft. height × 200 ft. diagonal

These figures are taken under actual operating conditions and include average operating ability, interference, etc.

The Adcock D.F. equipment will have to cater for bearings over a range of 100–150 miles. With the increase in speed of aircraft the effective vertical height of the trailing aerial system has rapidly become less and as a result the field strength to be expected from, for example, a Lockheed 10 aircraft cruising at 180 m.p.h. and employing an average aerial-circuit power of 40 watts would be of the order of 2 μV/m. at 100 miles. With the average Adcock station a signal of 2 μV/m. represents a goniometer swing of ± 5° for an accuracy of ± 1°, and good bearings could be obtained provided no difficulties due to atmospherics or adjacent area interference were experienced. The airport area traffic channel employs D.F. characteristics primarily for elimination of interference, but occasionally demands are made on this channel for leading bearings to the airport while the aircraft is still some considerable distance away. This practice is not encouraged; leading bearings are usually given over short distances on the local zone channel.

If no long-range D.F. service is required of the area traffic channel, screened-loop aerials 4 ft. in diameter are usually employed; the same applies to the local zone channel where short ranges are expected. These loop aerials have an effective height of approximately 0·09 metre. The receivers employed are of the superheterodyne type, which, with 1 μV input induced in the loop aerial, gives a signal/noise ratio of 3·9 db. at $\pm 2\frac{1}{2}°$ from the null point. As a result a field strength of 11 μV/m. is required. Usually with ranges of 20–30 miles for a zone service this field strength can be expected from an average aircraft on fixed aerials, but if a greater range is required or if provision has to be made for the smaller aircraft then open loops of suitable dimensions giving a gain of up to 10 db. have to be employed.

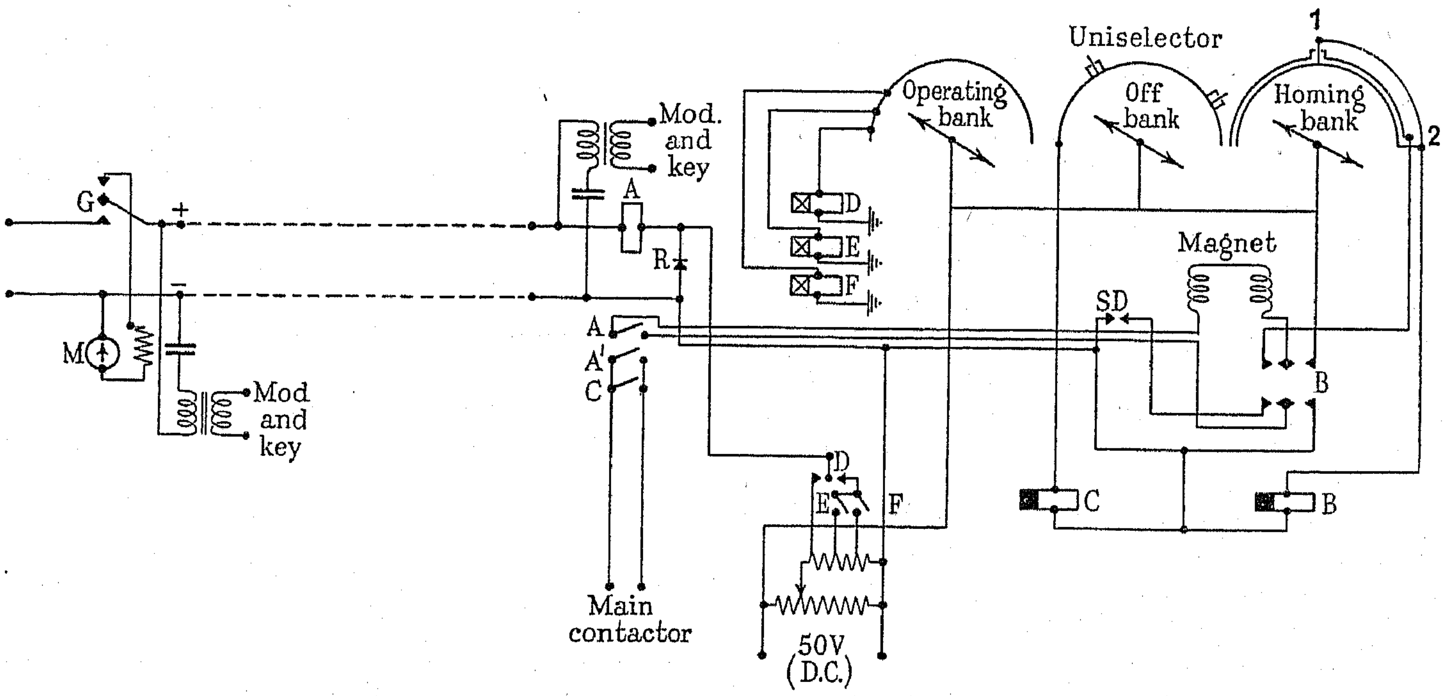

Fig. 10.—Step-by-step remote-control system.

This is particularly the case with respect to the ZZ D.F. channel where, although ranges may be short, a very high speed of operation and high order of accuracy are required.

Table 2 gives the gain in decibels for various dimensions of open loops over the screened loop after allowing for loss due to mis-matching of loop and goniometer inductance, and the approximate field strength required for various types of D.F. stations.

Apart from sensitivity, selectivity, signal/noise ratio, etc., D.F. receivers must be easy to operate and free from operational fatigue. Reliability (mechanical and electrical) and accessibility need no emphasis.

In one receiver in use, arrangements are made by switching the field coils in addition to the introduction of the sense e.m.f. to give sense indications in the same quadrant as the bearing, thus enabling speedier operation to be obtained.

Transmitters

The requirements for the transmitters employed for the aeronautical or short-wave circuits are:—

(1) Stability to meet the requirements of the Cairo recommendations.
(2) Reliability.
(3) Ease of adjustment and maintenance.
(4) Accessibility.
(5) Ease of power control.
(6) Remote control by as few lines as possible.

All high-frequency transmitters are, of course, crystal-controlled, but so far this method has not been employed on the medium-frequency band. Remote-control frequency-change is often required and this, combined with the need to remote-control all functions, viz. change from C.W. to telephony, change of power, etc., necessitated the use of a large number of remote-control lines with resultant heavy cost for line rentals. To reduce the number of lines a system of remote control by step-by-step mechanism has been developed, with the result that one or two pairs of lines at the most suffices to control all functions on any one transmitter.

The basic circuit is shown in Fig. 10. The remote-control unit comprises an automatic telephone dial G and a meter M for back indication. The transformer T supplies the modulating speech frequencies in the case of telephony or a frequency of about 800 c./s. from a local oscillator, which is used for keying on C.W. telegraphy, i.e. voice-frequency keying on the lines. The microphone circuit and oscillator are not shown.

When the contacts G to the positive supply are closed the relay A closes and the uniselector rotates to the zero stepping position by means of its self-drive contacts S–D.

At the zero position the slow-release relay B operates and alters the self-drive circuit to be responsive to impulses from line relay A. Thus on the first rotation of the dial to the stop the uniselector homes to either of the contacts 1 or 2. These are the zero stepping points, the bank of contacts being divided into two groups to save time and wear. On releasing the dial the impulses received step the uniselector to the required contact, operating relays D, E, etc., according to the number of digits dialled.

Contact A1 on the line relay A brings in the main power supply via a contactor, on the first dial operation. This contactor is subsequently held in by contact C from relay C in the "off bank."

Relays D, E and F, etc., may operate the C.W./R.T. circuits, power control, frequency-change circuits, etc., and, in order to indicate at the remote end the function dialled, contacts D, E and F are closed by these relays in suitable order, to place on the line potentials for the operation of the meter M, rectifier R being used as a stop. The H.T. supply to relays, and such others as need be, can be of the self-locking type with trip contacts in circuit with relays operated from the "off bank" of the uniselector. The relay C in the "off bank" opens contact C when released and all power supply is cut off, the uniselector remaining at the "all off" point O until the dial is again operated, when it rotates once more to the zero stepping point.

In Fig. 11 is shown a circuit using two pairs of lines. The functions performed are:—

(1) Filaments and intermediate power on.
(2) H.T. on.
(3) Full power.
(4) Half power.
(5) C.W./Telephony.
(6) Keying and modulation.
(7) Frequency 1.
(8) Frequency 2.
(9) Frequency 3.
(10) H.T. off.
(11) All off.
(12) Back indication of all functions.

Normally some 10 pairs of lines would have been required, whereas in the circuit shown all functions are carried out on 2 pairs.

Frequency-change is carried out in this case by providing 3 preset circuits covering the frequency band required and switched into circuit by switches placed on a common shaft and driven by a small geared motor, operated by any one of 3 relays brought into circuit by the uniselector. A cam on the motor shaft cuts off power after the requisite degree of rotation, and at the same time applies a brake and indicates on the back-indicating circuit the frequency in operation.

All relays operated by the uniselector are of the slow-response type so as to prevent operation during the passage of the uniselector wiper over unwanted contacts. The two examples shown employ single-digit dialling, but by employing, for example, 2-motion selectors, additional remote-control facilities may be provided.

Transmitters must be accessible, particularly the power supply circuits, where fuses and all power relays and contactors, keying relays, etc., should be readily removable and correctly marked.

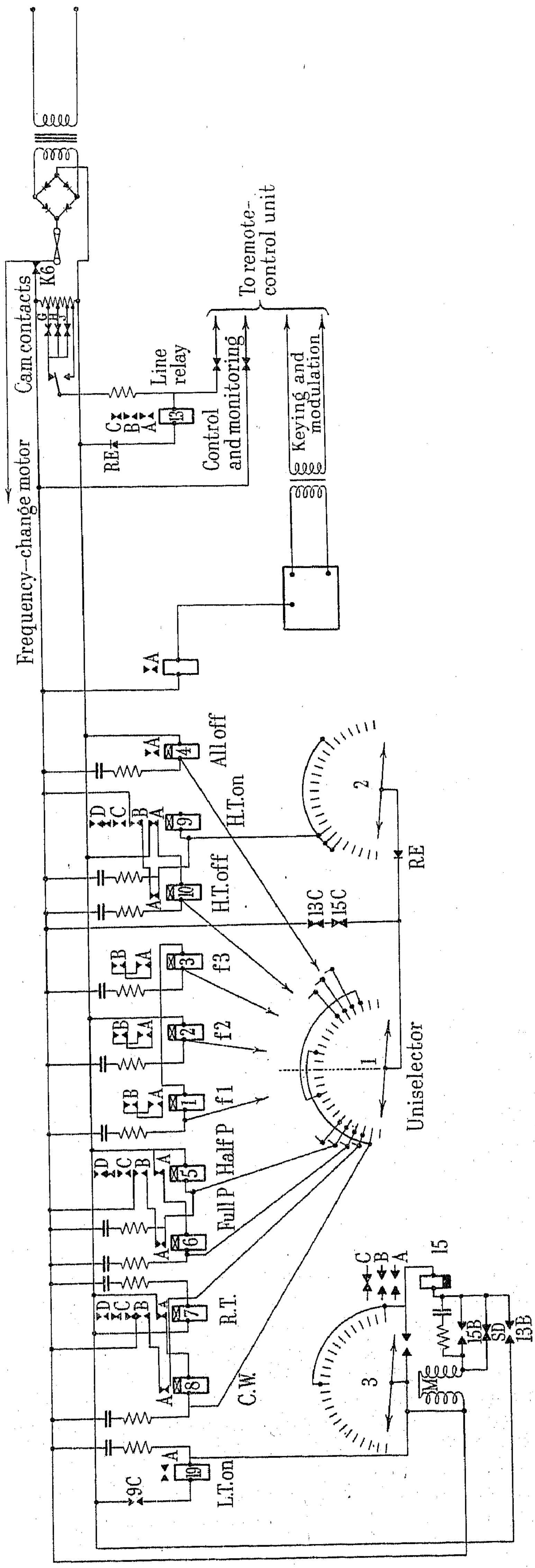

Fig. 11.—Step-by-step remote-control system.

Power supply by rectified alternating current is preferable to employing rotating machinery.

So far as the high-frequency circuits are concerned, freedom from key-clicks, chirp and spacing-wave radiation is absolutely essential, " listening-through " working is usual, and thus keying must be clean and free from any spacing wave and radiation from the master oscillator. Circuits avoiding neutralizing adjustments are preferable, and of course direct-coupled aerials should not be employed because of the spreading and cross-modulation likely to occur owing to the proximity of aerials and other transmitters working on closely neighbouring frequencies. A good tank circuit and inductive coupling to a separate aerial circuit is essential. Harmonic radiation should be as low as possible. In cases where transmitter and receiver are adjacent, arrangements are made to short-circuit or detune the transmitter aerial during reception.

The power employed in the aerial circuit is:—

(1) For aeronautical area channels, 0·25 kW.
(2) For aeronautical zone channels, 0·025–0·05 kW.
(3) For omni-directional beacons, 0·50–1·00 kW.
(4) For high-frequency channels, 0·20–0·25 kW.

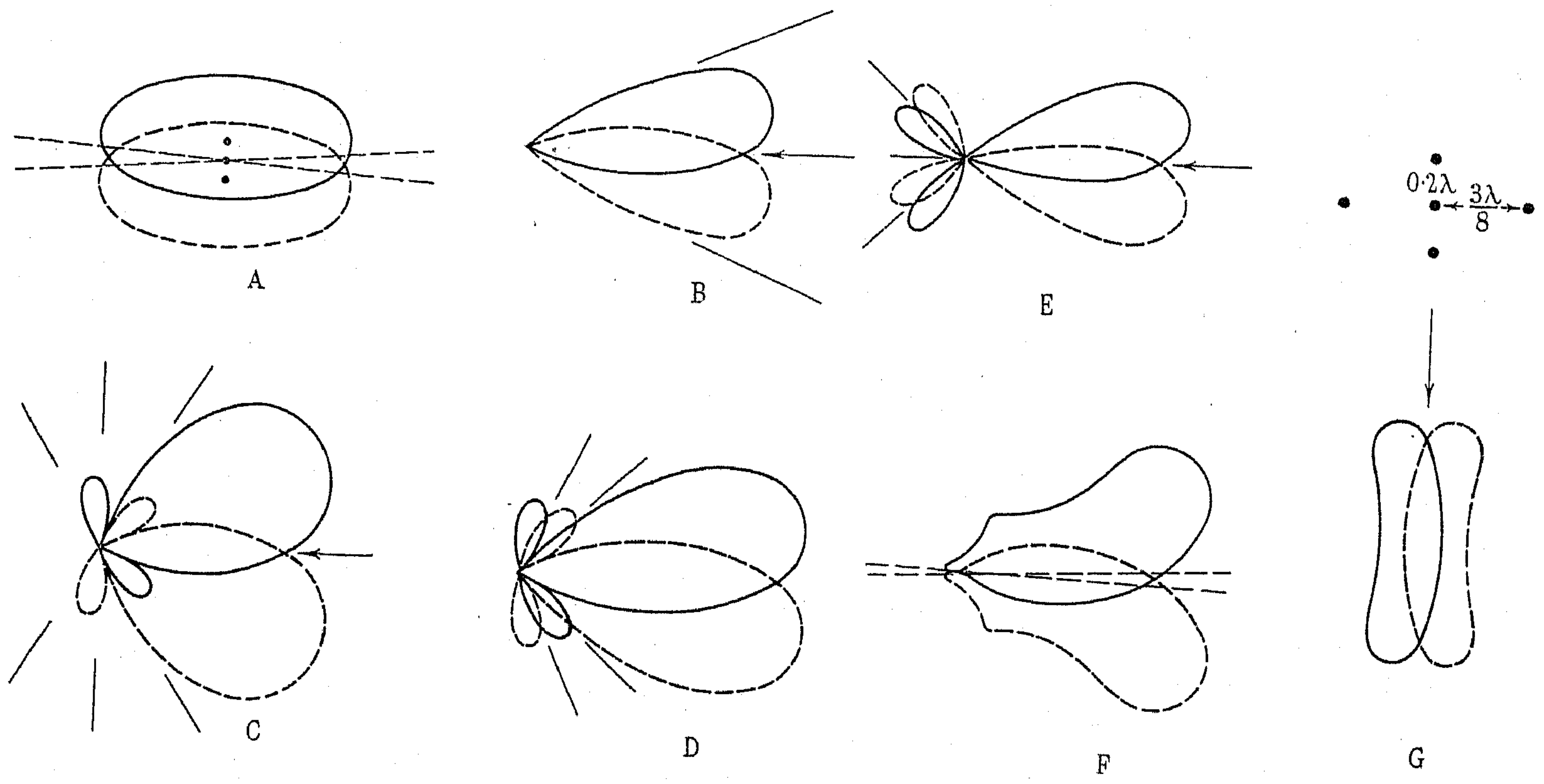

Fig. 12.—U.H.F. approach beacon polar diagrams.

Ultra-High-Frequency (u.h.f.) Landing Devices

Experimental work on u.h.f. directional beacons for landing and approach assistance was first commenced in the U.S.A., but the first practical equipment—operating on 33·3 Mc./s.—was produced by A. G. Lorenz.

Although claims have been made for complete blind landings, no such landings with commercial aircraft and passengers have been made in this country.

The equipment consists of a main beacon and two marker beacons, the radiation pattern of the main beacon in a horizontal plane being as shown in Fig. 12(A). Various efforts have been made to produce a unidirectional path and also to reduce the field strength in directions other than along the equi-signal path in order to reduce interference. The ideal pattern would be that shown in Fig. 12(B). Attempts have been made to reach this ideal by means of directive aerials, but normally such aerials, while capable of very sharp major lobes, are attended by small minor lobes, and the sharper the main lobes the greater the number of minor lobes; also the use of reflectors increases the minor lobes. The power lost in the minor lobes, and the interference which might be caused, are not so important as the fact that they can cause quite serious false courses, owing to the effect of ground attenuation. Numerous calculations and tests have been made with the radiation patterns shown in Figs. 12(C), 12(D) and 12(E), the false courses being marked. In the case of (c), attempts to produce an aerial system in which one radiating system would embrace the minor lobes of the other were not very successful.

The effect of ground attenuation with regard to false courses is shown below. If the field strength at 15 miles and 1 500 ft. produced by a given power is taken as a reference level, then

— 20 db. will give the same field strength at 12 miles.
— 40 db. will give the same field strength at 8·75 miles.
— 60 db. will give the same field strength at 5·8 miles.
— 80 db. will give the same field strength at 2·8 miles.

Therefore if no false courses were to be noticeable over a range of 3–4 miles, bearing in mind that at 15 miles the aircraft equipment should be capable of enabling an approach to be commenced, the power radiated on false courses would have to be reduced by more than 80 db. In Fig. 12(F) is shown the radiation diagram of one beacon system employing a series phase aerial system which has been tested at Croydon. In this case there are no false courses, but a reduced equi-signal path 180° from the main path and a reduction in radiation at 90°.

The choice is, therefore, between two equal equi-signal paths and considerable radiation at 90°, and partial unidirectivity with reduced radiation at 90° and a small equi-signal path at 180°.

False courses and distorted equi-signal tracks are often caused by the proximity of buildings, steel structures, etc., and therefore the site for a landing beacon has to be very carefully chosen. One beacon system has been produced in which a measure of course adjustment can be obtained by adjusting the currents and phase in the components of the aerial system. (The aerial systems at present in use do not easily allow of such adjustment.) Fig. 12(G) shows a plan view of the aerial system and the radiation diagram.

Marker beacons are more or less standard in their characteristics and give a single vertical lobe of radiation. Although at first experiments with a central null point were made, this was dropped in favour of a single maximum signal.

The modulation and keying frequencies adopted internationally are:—

Modulation frequency

Main beacon.	1 150 c./s.
Inner marker.	1 700 c./s.
Outer marker.	700 c./s.

Keying

Main beacon.	dashes	0·875 sec.
	dot	0·125 sec.
Inner marker.	dashes	0·067 sec.
	space	0·1 sec.
Outer marker.	dashes	0·4 sec.
	space	0·1 sec.

A word may perhaps be said about the construction and installation of u.h.f. beacons. Accessibility is most important and the equipment should be robust and free from trick circuits requiring highly skilled maintenance. Ample room in the building housing the equipment is essential for adequate maintenance, particularly in the case of the marker beacons where there is a tendency to place the equipment in a " dog kennel " under the aerial system; servicing such equipment in bad weather is very difficult. Thermostatically-controlled heating of the entire building is very desirable.

Remote-control lines should be well protected and if possible should not be run through common junction boxes and telephone exchanges.

Although Croydon is not an ideal site for the use of u.h.f. beacons for completely blind approach, horizontal guidance by means of the equi-signal path and positions indicated by means of the marker beacons has been very successful. Fog and wind may not as a rule occur together, but bad visibility, low cloud and high winds are a frequent combination and thus more than one beacon path may ultimately be required at main airports.

While landing and approach beacons facilitate landing in bad visibility, consideration must be given to the reliability of, for example, the glide path and its use so that the maximum benefit may be obtained from the process of speeding-up landings in such conditions. The time taken in landing has already been indicated as one of the causes of congestion in the communication system.

(3) AIRCRAFT RADIO EQUIPMENT AND INSTALLATION

No matter how extensive the ground organization may be, and no matter how varied the facilities provided or the steps taken to provide the maximum possible efficiency, the successful operation of the communication system depends to a very large extent on the aircraft equipment and installation.

At first the only equipment carried comprised a medium-frequency transmitter, receiver and trailing aerial. Now a much more comprehensive installation is provided. But whereas the technique and design of equipment has improved out of all recognition during the last 5 years, the improvement in installation and accommodation and provision for radio services in the aircraft has not been so marked.

Perhaps it may be permissible to stress at this point the need for adequate accommodation for the aircraft installation, because the performance of the best equipment in the air and on the ground can be ruined by inadequate accommodation. The radio officer on the aircraft has a difficult function to perform, and necessarily under far from ideal conditions. In the same way that freedom from fatigue has to be considered in the ground station, so must careful consideration be given to the matter in the aircraft installation, where the operation of the equipment is so much more difficult. Adequate accommodation must really be considered during the design of an aircraft. The pilot of an air liner now relies to an extremely large extent on the operation of his radio equipment, and it is essential to have the best layout and accommodation possible in order to give a good service and create a high degree of confidence. An aircraft in fog with poor communication is a nuisance to others and slows up the operation of the entire system.

The equipment required on an aircraft depends, broadly, on the routes over which operations are to take place.

For European service the complete installation will generally comprise the following items:—

(1) Medium-frequency C.W. telegraph transmitter operating on a series of preset or easily adjustable frequencies ranging from 500 to 300 kc./s.

(2) Medium-frequency receiver covering from 500 to 200 kc./s.

(3) D.F. receiver or homing system, employing fixed or rotating loops; frequency range 1 500 to 250 kc./s.

(4) U.H.F. approach and landing beacon receiver.

More often than not in the case of Empire routes, item (4) would be omitted on flying boats, but some land planes on the North Atlantic route, for example, would employ landing beacon equipment.

(5) Power supply system.

To this would be added for operation on the Empire routes:—

(6) H.F. transmitter covering the mobile bands in the frequency range from 15 Mc./s. (often combined with item 1 in an m.f./h.f. assembly).

(7) H.F. receiver covering the same frequency range and sometimes as far as 1·5 Mc./s.

(8) On long-distance aircraft an emergency equipment is often desirable.

The general requirements for equipment are as follows:—

Transmitters.

Stability to meet the requirements of the Cairo Conference, viz.

10–550 kc./s., ± 0·3 %
1·5–30 Mc./s., ± 0·025 %

This stability to be obtained over a wide temperature range.

Very good rigidity and freedom from frequency modulation through vibration.

Ability to operate safely at low pressures and temperature and high humidity.

Good accuracy of calibration.

Accessibility of components and controls, with a very high order of reliability in construction and insulation.

Receivers.

Stability is as important in receivers as in transmitters. Good rigidity, accuracy of calibration, freedom from frequency modulation through vibration, accessibility (particularly of preset circuits), ease of adjustment and tuning and of access to valves. Adjustable selectivity, and sensitivity on medium frequencies of the order of 5 μV for 10-mW output, are the usual requirements.

Most receivers are of the superheterodyne type with ganged tuning controls and fixed or variable beat-frequency oscillators operating at intermediate frequency. Automatic and manual volume controls are usually provided.

Power supply.

Operation at high altitudes, ample rating for intermittent operation, high insulation, lowest possible percentage ripple and highest efficiency possible.

Needless to say, in all items low weight and small dimensions are of paramount importance. At the same time there must be a limit to the demands made for low weight and small size. A high order of performance is required and it must be appreciated that a reliable equipment can and will result in a saving of time in bad weather, apart from the major issue of safety, and the saving in time alone may compensate for any additional weight carried, in order to ensure the greatest reliability.

Extreme lightness at a sacrifice in performance and reliability should not be the aim.

Transmitter power and field strength.

Curves showing field strength and distance plotted for various values of metre-amperes are shown in Fig. 13 for a frequency of 333 kc./s. and transmission over average ground and sea.

Under good conditions the area D.F. stations require a field strength of 2 μV/m. in order to give bearings with an accuracy of the order of ± 1°, but during the summer months under conditions of static interference much higher field strengths are often required. To provide a D.F. accuracy of ± 1° at 100 miles (about the distance of the French coast from Croydon) under fairly good summer conditions, field strengths of the order of 5 μV/m. would be necessary, the metre-amperes required to give this field strength being 6. Under the worst conditions of static, communication ranges may be down to 10 miles. Under poor conditions, i.e. during 20 % of the summer period, a field strength of 10–12 μV/m. may be required for an accuracy of ± 1°. Under these conditions with 6 metre-amperes the D.F. range would be reduced to 50–60 miles. With large aircraft and low speeds, a 200-ft. trailing aerial will provide an effective vertical height of 10 to 12 metres and there is no difficulty in providing the requisite power. With increasing speeds, however, the effective height rapidly becomes less and at 200 m.p.h. is less than 2 metres; the power delivered by the transmitter must therefore be increased.

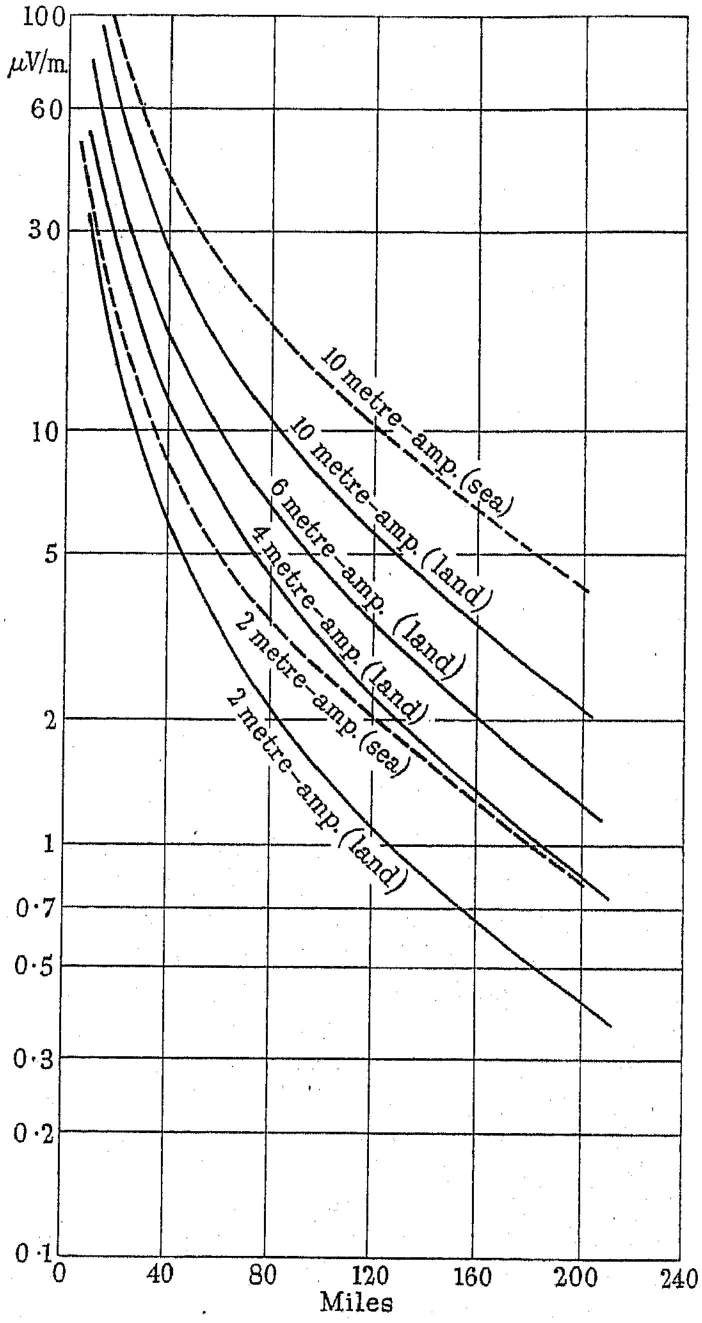

Fig. 13.—Curves showing field strength for various values of metre-amperes at 333 kc./s. over average ground and sea.

At high speeds the weight and drag of the trailing aerial become a serious consideration, and in view of the low effective height obtained the aerial is not very efficient. In addition, in 90 % of the cases of static discharge the trailing aerial has been mainly affected. Furthermore, the use of a trailing aerial in high-altitude aircraft presents considerable difficulties. On most aircraft it is not difficult to provide a fixed aerial of effective height little different from that of the trailing aerial.

The weight of the trailing-aerial equipment can then be allowed against the increase in weight of the transmitter required to provide additional power.

The general tendency on modern aircraft is to fit a fixed aerial only, but there is also a tendency to use the smallest possible fixed aerial, on the grounds of presenting the least possible drag. This results in the need for still greater power, and if the high voltages involved do not first become the limiting factor the additional weight will probably more than offset the saving in drag, and in any case the installation presents a very difficult problem.

Table 3 shows the aerial current, power and voltage for various effective heights for the conditions of 5 μV/m. at 100 miles over average land, i.e. 6 metre-amperes, and assuming an aerial capacitance in all cases of 200 $\mu\mu$F and a total circuit resistance of 10 ohms.

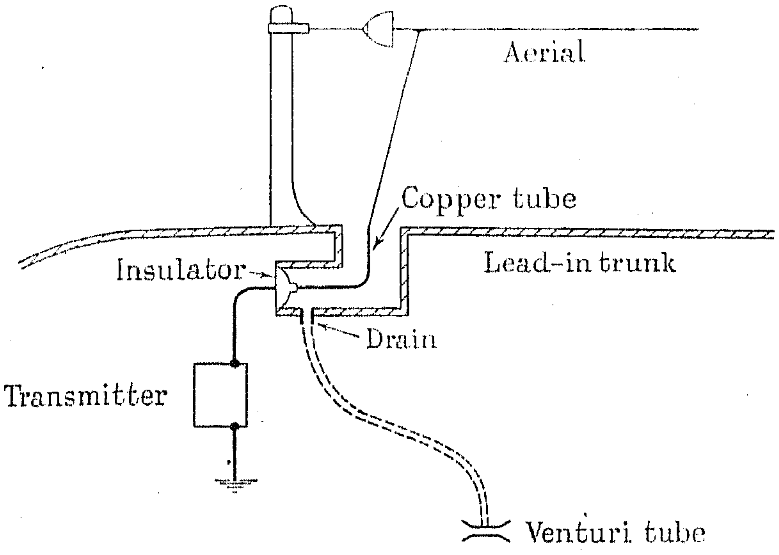

Fig. 14.—Lead-in insulator arrangements.

An effective height of 1·5 m. is the lowest that can be tolerated if the value of 6 metre-amperes is to be maintained.

On medium and large aircraft no difficulty should be experienced in providing an effective height of 1·5–2 m. On the small aircraft as used on internal routes, however, a lower value of metre-amperes will have to be accepted. Existing aircraft operating on the internal routes cruise at speeds of the order of 120–140 m.p.h. and make use of trailing aerials with an effective height of 4–7 m. The fixed aerials, however, only enable a metre-ampere value of 0·5 or less to be obtained, and as the fixed aerial is extensively used during the last 30 miles of approach during bad-weather operation, the accuracy of direction-finding on the zone channels is sometimes rendered difficult until ranges of 8–10 miles are reached.

The ranges required on short waves are of course considerably greater, but here the efficiency of the aerial system is very much greater and the problem of range becomes one of the correct frequency, stability, and freedom from frequency modulation rather than of power. Needless to say, adequate bonding of airframe and engines, etc., and adequate screening and suppression of ignition and of all electrical interference is of paramount importance to the performance of the complete radio installation.

Table 3

Effective height	Aerial circuit		
	Current	Power	Terminal voltage
m.	amp.	watts	kV(r.m.s.
0·5	12·0	1 440·0	33·0
1·0	6·0	360·0	16·6
1·5	4·0	160·0	11·0
2·0	3·0	90·0	8·3
2·5	2·4	57·5	6·7
3·0	2·0	40·0	5·6

With powers of the order of 200 watts in the circuit of a fixed aerial of rather low capacitance, adequate insulation is of course essential; care must be given to the arrangement and location of lead-in insulators and, of course, to the aerial insulators. The disposition of the aerial and earth leads inside the aircraft can materially affect the efficiency of the installation. They should be as short as possible. One ingenious arrangement of lead-in insulation is shown in Fig. 14. A trunk is led into the fuselage with the insulator at the end, and a drainage pipe attached to a venturi tube draws off any moisture. The trunk may be heated.

The arrangement of the output circuit of the transmitter is important as a very low value of resistance with high inductance is required and a high voltage exists across the inductance. The requirements can be met,

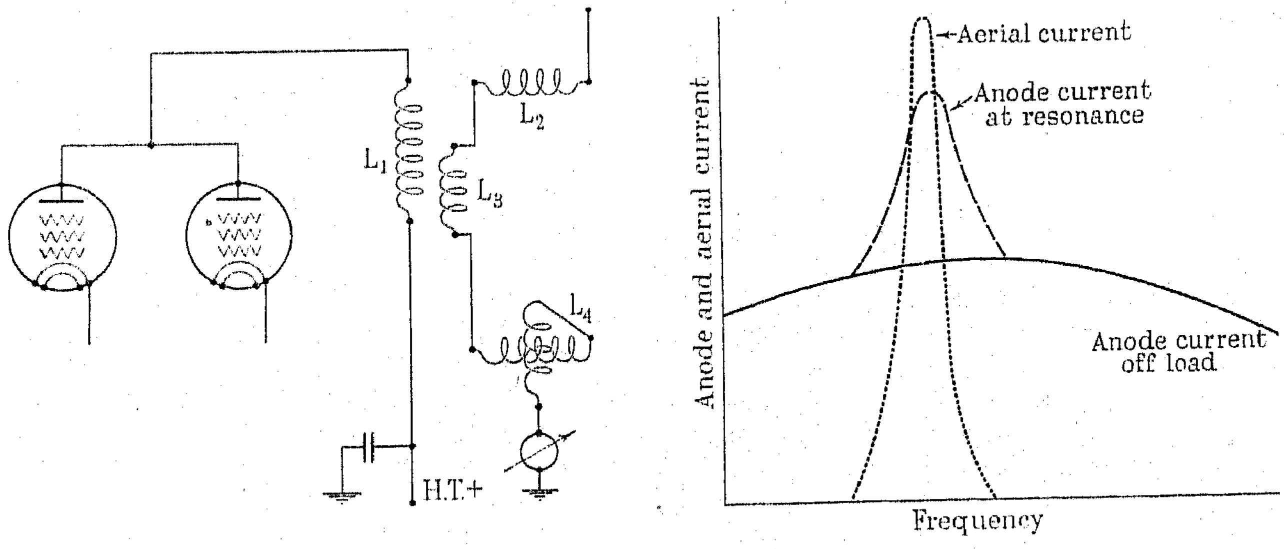

Fig. 15.—Transmitter output-circuit arrangements.

however, by the employment of high-grade porcelain and by care and attention to smooth and rounded surfaces of all connections, etc.

With high powers, particularly when pentode valves are employed with heavy grid drive, loss of the aerial, or short-circuit due to breakage or ice, may result in an excessive dissipation of power at the anodes of the valves. The circuit shown in Fig. 15 is therefore often used. L_2, L_3 and L_4 comprise the aerial tuning inductance, L_2 being very tightly coupled to L_1. L_1 is arranged in conjunction with the valve and stray capacitances to resonate in the middle of the frequency spectrum required, and thus by itself presents a high impedance to the valves. A typical resonance curve is shown. When the aerial circuit is tuned to resonance, power is transferred to the aerial circuit and the valves draw their correct anode current. Under any other conditions a minimum anode current is drawn by the valves and the anode dissipation is not exceeded.

Representative Equipments and Installations

The fixed aerial on a Douglas D.C.3 is representative of a fairly good and effective system on an average aircraft. This aerial in practice has an effective height of about 2 metres. It may be interesting to note that the actual height above the fuselage is only 1 metre; the gain appears to be due to the fact that the aircraft is a low-wing monoplane of good conductivity and the height of the fuselage above the wings adds to the effective height.

The installation on this type of aircraft employed by the K.L.M. line is perhaps a good example of a high-power transmitter operating into a fixed aerial, and of an installation employing combined medium- and short-wave equipment, D.F., etc.

The equipment comprises:—

(1) Transmitters, m.f. and h.f. combined.
(2) D.F. receiver.
(3) Rotatable loop and scale.
(4) High-frequency/medium-frequency receiver.
(5) Power supply system.
(6) Control box.

The transmitter is designed to work on 9 spot frequencies, i.e. 5 medium frequencies and 4 high frequencies. These are at the moment 500, 348, 333, 327 and 322 kc./s., and 17 281, 11 385, 8 333 and 5 693 kc./s.

The high frequencies are crystal-controlled, but provision is made for adjustable master-oscillator control without crystals, for small variations of frequency, to avoid interference.

On medium frequencies and with a fixed aerial capacitance of 170 $\mu\mu$F an aerial-circuit power of 200 watts is produced, and with the effective height of 2 metres a metre-ampere value of 9 is obtained. On high frequencies the aerial power is 40 watts. C.W. and M.C.W. telegraphy is provided, no provision is made for telephony, and a reduction of power to one-tenth is provided for. On the medium frequencies the frequency constancy is $0 \cdot 25\ \%$, while on the high frequencies the crystals are ground to an accuracy of $0 \cdot 02\ \%$. Between 17 and 36 metres the stability is $0 \cdot 02\ \%$ and between 36 and 52 metres $0 \cdot 1\ \%$, for a temperature range of $-10°$ C. to $+40°$ C.

This equipment has a master-oscillator separator amplifier and output amplifier, frequency multiplication being performed on the high frequencies. Screened pentode valves are employed.

In Fig. 16 (Plate 1, facing page 336) is shown an internal view of the transmitter. This illustrates the care taken in the arrangement of inductances, connections, switches, etc., in view of the high voltages involved.

The transmitter is supplied with power at 12 volts for filaments, and 350 and 1 625 volts for high tension. The H.T. supplies are obtained from a rotary transformer operating on 12 volts and taking a total of 60 amperes.

The construction is very rigid, a single cast-aluminium front panel being used for the main assembly. Controls are very robust and simple, a single handle being employed for changing to any spot frequency.

The h.f./m.f. receiver covers the frequency bands 545–240 kc./s. and 18 750–5 454 kc./s. The medium-frequency sensitivity is 4 μV for 10 mW output and on high frequencies 25 μV. At these figures of sensitivity the noise level is 1 mW. Variable band width between 6 and 10 kc./s. is provided.

The D.F. receiver is a very comprehensive type and provides cardioid, figure-of-8 and omni-directional reception and also medium-frequency landing beacon reception.

The practice of carrying a separate receiver of this type has much to commend it, as it provides a standby service for navigational assistance should the transmitter fail, apart from its use for general navigational purposes.

The transmitter dimensions are 24 in. × 21 in. × 11 in. and the weight is 97 lb. The m.f./h.f. receiver and D.F. receivers are of similar dimensions and weight, viz. 6·7 in. × 19·3 in. × 9·9 in., and 21·8 lb. The total weight of the complete installation is 230 lb.

A typical installation on an Imperial Airways "C" class flying boat (Fig. 17) comprises:—

(1) Transmitter.
(2) Receiver, combined m.f., h.f. and D.F.
(3) Control unit.
(4) Power supply.

This equipment provides for operation on both fixed and trailing aerial.

The transmitter covers the frequency bands 20 000–1 500 kc./s. and 545–273 kc./s. 6 frequencies may be preset; crystal control is not provided.

Transmissions on C.W., M.C.W. and telephony is catered for, the output power to the trailing aerial being for telegraphy approximately 60 watts and for telephony 30 watts, giving approximately 9 metre-amperes on telegraphy.

A straight master-oscillator and output amplifier is employed without a separator amplifier.

The receiver covers the frequency-ranges 20 000–3 000 kc./s., 1 639 kc./s. 1 000–667 kc./s., and 500–150 kc./s., and has a sensitivity of 20 μV for 10 mW from 20 Mc./s. to 3 000 kc./s. The medium-frequency selectivity is:—

2 kc./s. off tune	.. ..	— 6 db.
10 kc./s. off tune	.. ..	— 60 db.

Direction-finding with rotatable loop is provided, both aural and visual indications being given. " Homing " with the loop fixed is also available.

The complete equipment operates from a 12-volt supply by the aid of rotary transformers, and weighs approximately 200 lb.

In Fig. 18 is shown the radio installation of the Pan American Airways flying boat used on the North Atlantic route. Three complete transmitters and receivers are provided, one pair on medium frequencies for long-range telegraphy, one pair on high frequencies for long-range telegraphy, and a short-range telephone equipment on high frequencies. Rotating-loop direction-finding is also provided. All receivers and controls are installed in front of the operator, the medium-frequency transmitter being in the nose of the ship and the h.f. telegraph and telephone equipment, with all batteries, etc., in the amidships compartment above the cabin. The installation is exceptionally neat and accessible and is ideal from an operating point of view. The typewriter should be noted, and also the seat provided for the operator.

Aircraft Electrical Power Supply

The problem of electrical power supply on aircraft is one of the most difficult, particularly where the radio interests are concerned. The subject of power supply in general has been dealt with in the paper by Messrs. Chaplin and Nixon (*Journal of the Royal Aeronautical Society*, December, 1939).

The practice at the moment on medium and large aircraft is to provide two engine-driven generators supplying a power of 1 kW each at 14–16 volts for battery charging, but to provide a battery of ample capacity is not easy when it is realized that this battery has to provide all the electrical power required for starting. While operation in flight can be so arranged that all power is obtained direct from the generators with little or no drain on the battery, it is another matter entirely when circumstances are such that operation from the battery only is required.

On small aircraft, wind-driven generators are still used to provide power on both lighting and radio, while engine-driven generators are being applied to most medium-sized aircraft.

The problem in the main, therefore, becomes one of engine-driven generators (d.c. or a.c.) versus a completely separate power plant providing direct or alternating current, or both. The latter, perhaps, only becomes a possible solution of the problem when consideration is being given to large aircraft on long-distance routes. For aircraft on the European or similar routes engine-driven generators and batteries of adequate capacity are perhaps the best solution. Alternating-current power supply provided other than by means of a separate generating plant has the disadvantage that failure of the aircraft engines means failure of the radio service. This consideration also applies to emergency communication from the ground or water. Alternating current, considered purely from a radio point of view, has much to recommend it and at a frequency of 800 c./s. the weight of rectifier and smoothing circuits can be reduced to very economical limits. At the same time the weight of generators of equal powers shows a saving in favour of the alternator.

To sum up, the position appears as follows:—

(1) For large aircraft on long-distance routes:—

(*a*) A separate generating plant giving alternating or direct current, or

(*b*) Engine-driven generators supplying direct current, and a battery of reasonable capacity.

With regard to (*b*), it is worth considering whether a battery of 50 or even 100 volts might not be advantageous. The arguments for are:—

(*a*) Reduction of weight of the radio motor-generator.

(*b*) Reduction of weight in cables.

(*c*) Reduction of weight in miscellaneous motors, starters, etc., on the aircraft.

The chief argument against is that of danger, on the ground that a short-circuit might cause arcing, whereas such an occurrence on a low-voltage battery might not produce an arc. While this is true to some extent, a short-circuit on a low-voltage high-capacity battery can be very dangerous. Adequate safeguards for the higher voltage should present little difficulty.

(2) For medium and large aircraft on shorter routes such as those in Europe, engine-driven d.c. generators as in 1(*b*) are probably the best solution.

(3) For small taxi and private aircraft a smaller version of 1(*b*) is undoubtedly a better solution than wind-driven generators.

Finally, it is essential during the initial stages of design of an aircraft to give ample consideration to the power requirements of the radio equipment and not just to leave the radio service to do the best it can with what is left in an inadequate battery after engines have been started. Systems in which the radio performance depends on the use of cabin lights, landing lights, etc., should be avoided.

Direction-Finding on Aircraft

Mention has been made of direction-finding on aircraft and it might be interesting to consider briefly the growth of this equipment. Whatever the form and organization of direction-finding on the ground, the ability to take accurate bearings on the aircraft itself is of considerable value. One essential fact, however, must be kept in mind and that is that use of the D.F. equipment must not interfere in any way with the maintenance of the normal listening watch on the appropriate frequency.

Apart from the value to the ground organization as already indicated, the ability of the aircraft to make use of the omni-directional beacon system for navigation is in effect equivalent to a " standby " equipment in the event of transmitter or other failure.

In the early days, rotatable loops were used inside the fuselage, followed by a switching system with fixed loops or loops and open aerial which approximated to an equi-signal system.

Equi-signal systems have the very considerable advantage over null methods of aircraft direction-finding in that the ratio of signal to electrical and mechanical noise is greater in the former case, with a resultant increase in reading accuracy.

At first the loop-reversing switching system was carried out by hand, but the introduction of a motor-driven system permitted a visual indication to be employed, although it was not very easy to obtain steady readings. This difficulty was, however, overcome when valve or a.c. switching was employed, in which the visual " left-right " indicator takes the form of a phase-meter, giving a left-hand deflection if the switching component in the l.f. output is in phase, a right-hand deflection if in anti-phase, and no deflection at all when this component is reduced to zero by suitable orientation.

The most generally used type of modern D.F. equipment employs visual and aural reading with " sense " determination in the latter case and rotatable loops.

The overall sensitivity of aircraft D.F. receivers has of necessity steadily increased as the size of the loops employed has decreased, up to figures of less than 1 μV on equipments where the small streamlined loops are used. These consist of rotatable loops of 3–4 in. diameter encased in close-fitting streamlined housings. The drag is appreciably less than that obtained with 18–20 in. open screened loops. Moreover, there is much less chance of ice formation on the loop.

It will be appreciated that this increased sensitivity has only been made possible by the extremely advanced ignition screening and bonding systems that are being incorporated in present-day aircraft designs, chiefly American, and also by the recent developments in the elimination of atmospherics. Atmospherics, i.e. accumulated and due to rain static, have always given trouble on reception. The application of a suppressor developed in the U.S.A. has materially reduced this source of interference.

Electrical noise and bearing sensitivity.

Electrical noise is the limiting factor in all D.F. systems. The following figures, taken from typical apparatus, will serve to illustrate the effect of noise.

Bearings can be read to ± 2° with the following signal/noise ratios at 2° off null:—

Aural (cosine) system—spot bearing	0 db.
Aural (cosine) system—swing bearing (± 10° swing)	− 9 db.
Visual system—spot bearing ..	− 18 db.

It should be noted that " zero blurring " has been included with the noise in arriving at these figures. It will be seen that the bearing reading accuracy is very considerably greater in the case of the visual system.

Visual versus aural Direction-finding.

The advantages of visual over aural systems may be summarized as follows:—

(*a*) Greater reading accuracy under conditions of severe electrical noise.

(*b*) Absence of acoustic interference.

(*c*) Separate " sense " determination unnecessary.

(*d*) Homing on to beacons possible. The instrument will eventually guide the aircraft to the desired beacon, even in the case of serious calibration error or bad navigation.

Against these advantages there is the disadvantage that great care in the design and installation must be exercised in order to guard against the possibility of reversed and inaccurate " left-right " indications.

Typical performance figures for an American equipment employing a 20-in. diameter loop aerial and valve switching at 105 c./s. are:—

± 1° with 5 μV/m. under favourable noise conditions.
Image ratio 80 db. at 300 and 1 000 kc./s.
Band width 20 kc./s. at − 60 db.

In addition to these forms of D.F. which employ a manually rotated aerial system, a direct-reading system has been produced in which the loop is continuously rotated by means of an electric motor. The effect of this, when a signal is being received, will be to modulate the output from the receiver at the loop rotation frequency in the case of cardioid reception, or at twice this frequency in the case of cosine reception.

The indicator consists of a moving-coil meter in which the field is made to rotate at exactly the loop frequency, or twice that frequency, according to whether cardioid or cosine reception is being used. The moving coil will take up a steady position according to the angle of maximum flux, which will correspond to cosine or cardioid maxima. The needle can therefore be made to indicate the bearing of a received transmitting station.

Tests to which Equipment must be Subjected

Reference to Air Ministry publications and leaflets E4, E5 and A7 of A.P. 1208, etc., will provide information on the tests to be applied and certain minimum requirements.

Reference to *Aero Digest* (January, 1939) and the U.S.A. C.A.A. reports will indicate the corresponding U.S.A. practice. The following quotation from *Aero Digest* is given as an example of the severity of tests to which American equipment is subjected:—

" *Vibration test.*

The apparatus is vibrated for 4 hours at a frequency between 30 and 60 c./s., with an amplitude of 0·25–0·5 in. and acceleration of 10 *g*. During a portion of this test the unit must be operated to check its performance. After the test it is visually inspected. The unit is then vibrated over a continuously varying range of frequencies, from 25 to 150 c./s., at a sufficient amplitude to make the vibration easily felt by touch. The change from 25 to 125 c./s. or vice versa may not be less than 125 sec. During the test, all component parts and structures are observed for resonant vibration, which is not permissible in approved equipment unless shown to be immaterial to satisfactory performance of the unit in service.

"*Drop test.*

At least 100 free drops are made, from heights varying from 6 in. to 18 in. No shock absorbers may be attached to the unit, but the impact may be dampened by sponge rubber not exceeding 1 inch in thickness, placed on the hard surface on to which the equipment is dropped. The apparatus is to be dropped so that it comes to rest in normal operating position. Transmitters should be operated during the test, as well as dropped in standby and inoperative conditions.

Plate 1

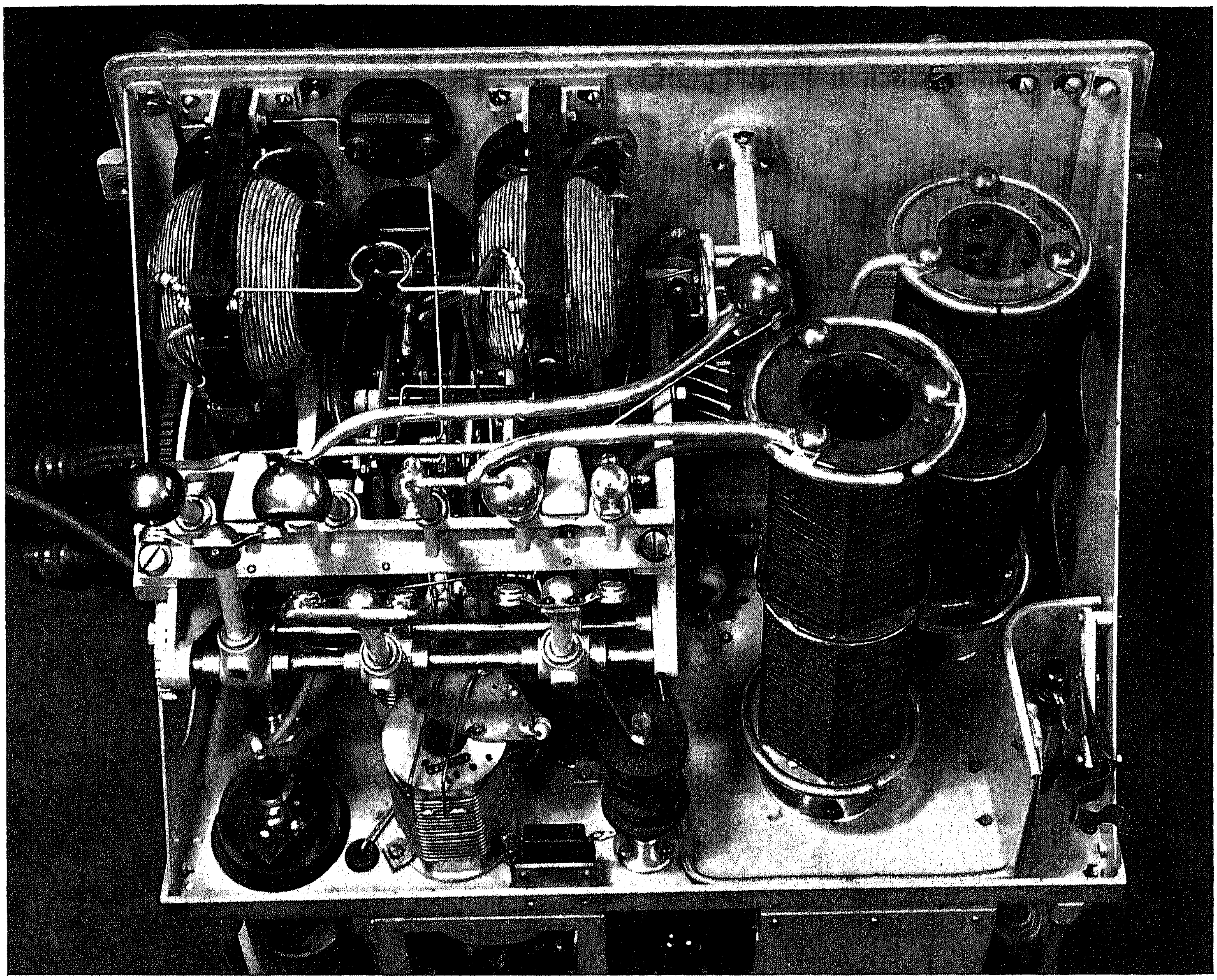

Fig. 16.—Internal arrangement of a typical high-power aircraft transmitter.

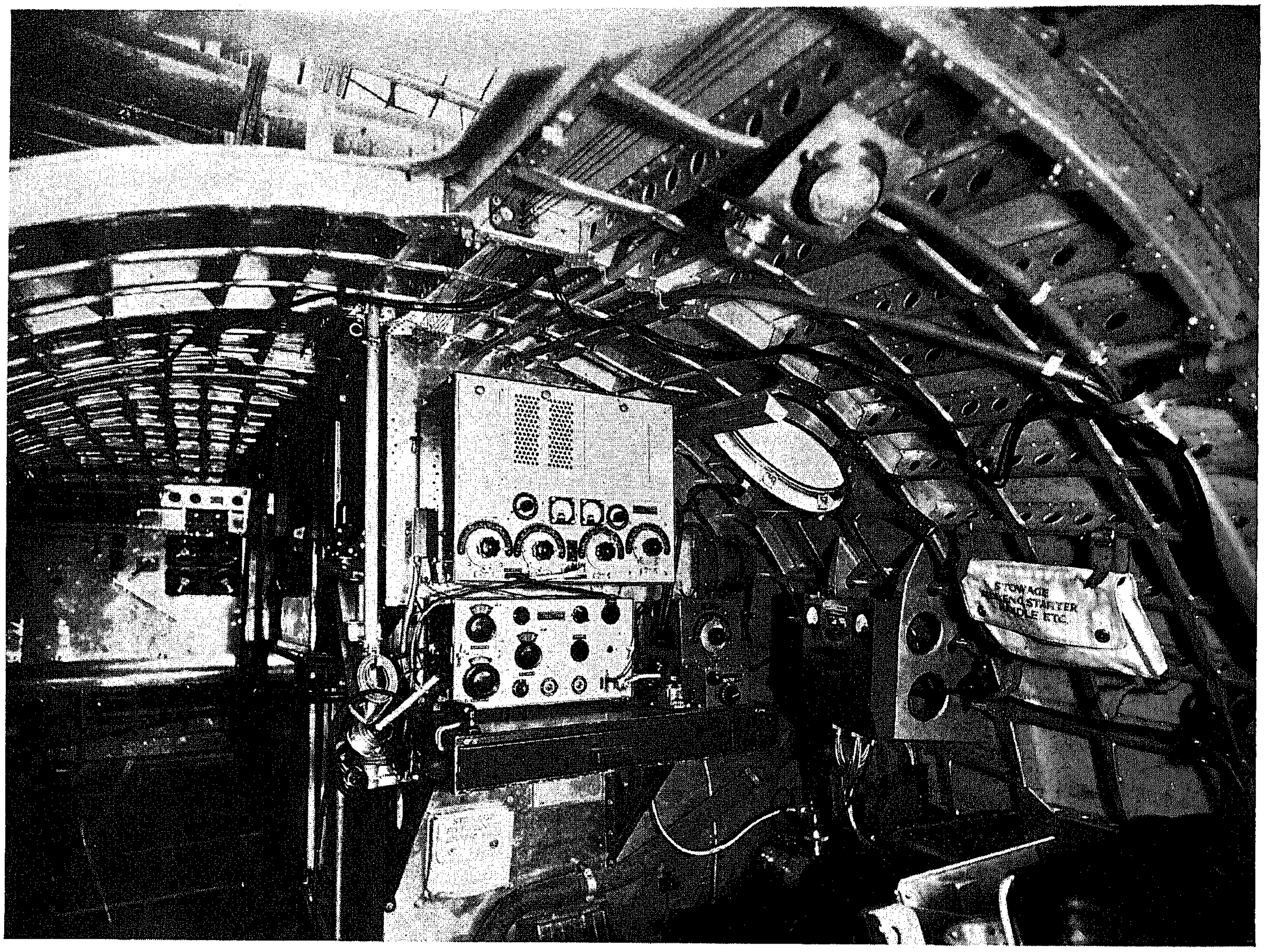

Fig. 17.—Installation in a "C" class flying boat.

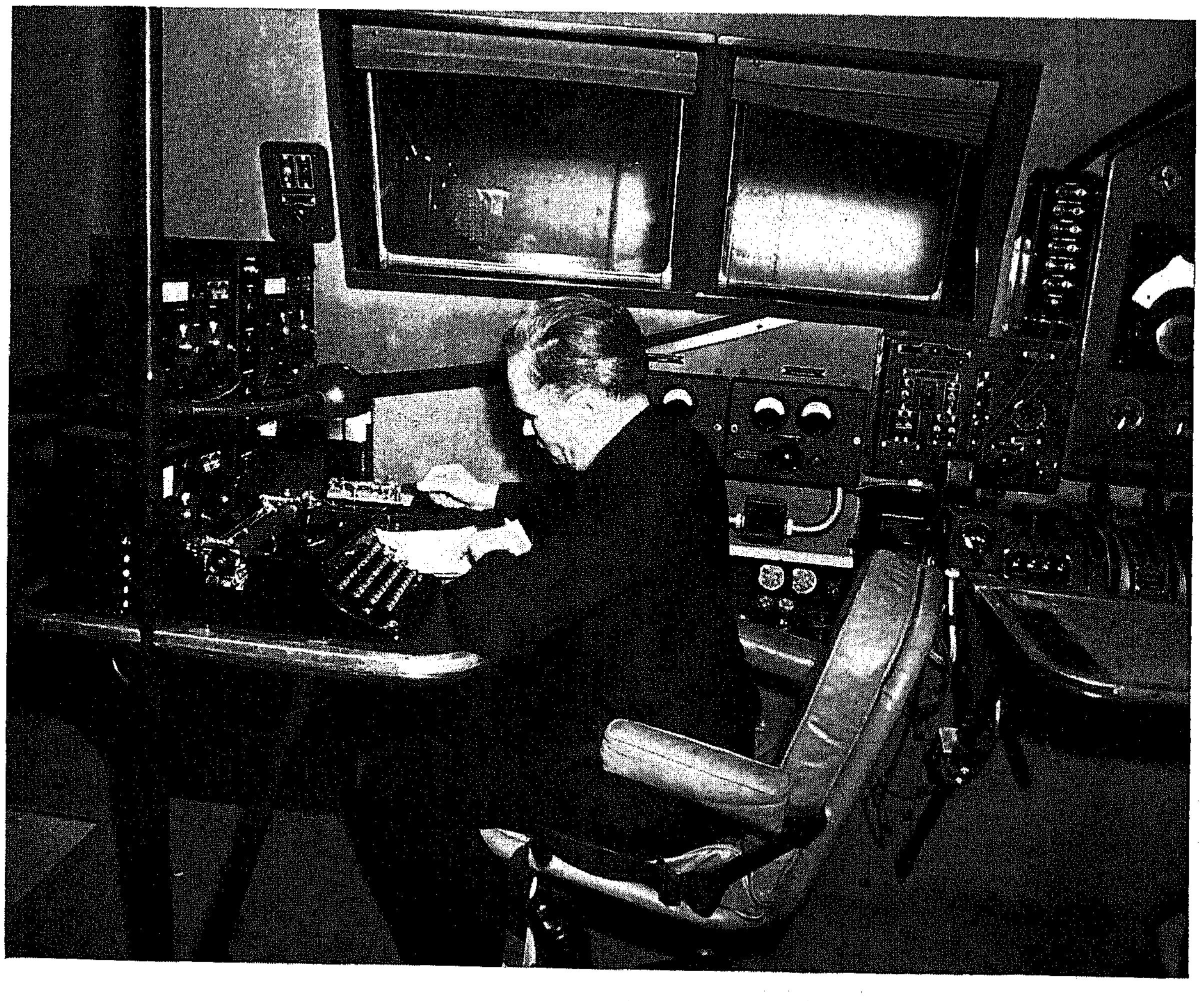

Fig. 18.—Installation in Pan American Airways flying boat.

"*Pressure test.*

The unit is then placed in a pressure chamber where it is operated under pressures ranging from 31 in. to 8·52 in. Hg, for a sufficient period to disclose any latent conditions which may prove detrimental in service at high altitudes. The pressure tests are carried out in a vacuum tank in which the complete equipment can be placed and observed during operation at reduced pressures and high or low humidity."

Importance of the Aircraft Installation

There is no doubt that the radio service is one of the most essential on the aircraft and one in which great reliance and confidence is placed. Therefore it is as imperative to give as much consideration to the facilities for the provision and use of this service as it is to the provision of other instruments. The equipment is essential and it needs an adequate radiating system for successful performance. While weight is a consideration it must be appreciated that low weight and reliability, not only mechanical but communication, are not necessarily synonymous. The radio-equipment power supply and accommodation should be as integral a part of the design and layout of the aircraft as the engine installation, and not an afterthought installed in any odd vacant space that may have escaped general attention.

(4) THE ATLANTIC AND EMPIRE ROUTES TO THE EAST

The Empire routes are essentially long-distance, and as such the communication system differs from the European system in that greater use is made of high-frequency communication channels. The parts of the route which are common to the general European network conform to that system, and, whereas the routes to Australia and South Africa do not depart so very materially from the general provisions and principles of the European routes, the transatlantic routes with a long sea crossing make demands for a very comprehensive communication system and for long-range navigational assistance.

The majority of the communication systems over the Empire routes are provided, staffed and administered by the Posts and Telegraphs Departments or other Government Departments of the territory over which the routes are operated. Thus the Indian Posts and Telegraphs have direct control over the stations allocated to aviation communication in India. The French, Italian and Greek stations, etc., are under their respective Government Departments. Medium-frequency communication and navigational assistance by Adcock-type D.F. stations is more or less general, and in addition broadcasts of positions are made at regular times from the aircraft on a high-frequency channel.

The terminal station in this country is Southampton, and, in Eire, Foynes. Foynes is the main station for the transatlantic northern route, and Southampton the starting and terminal point for both Empire routes to the East and the Northern and Southern Atlantic routes.

The Empire route to the East crosses France to Marseilles, then to Rome, Athens, Alexandria, etc.

In the case of the route to Marseilles or Lisbon, when arriving at or departing from Southampton, medium-frequency communication and navigational assistance is given via Portsmouth and the French aeronautical radio stations as for any normal European route. Southampton " Eastleigh " is a local zone station and in addition to its duties on the normal internal traffic also provides local zone service for flying boats landing at Southampton " Hythe." In addition a radio installation is provided in a diesel-engined pinnace which operates on Southampton Water during arrivals and departures of the boats. The function of this pinnace is to provide communication with boats during the marking of the arrival and departure area, for warnings of shipping movements, etc. D.F. facilities are not, of course, possible on this pinnace but aircraft can, if necessary, " home " on transmission emitted from it.

In addition to the medium-frequency equipment a high-frequency telephone service is provided, linking the pinnace to Eastleigh and enabling separate communication to take place between the traffic controls at Eastleigh and on the pinnace so that warnings of aircraft movements in the area can be communicated.

A high-frequency point-to-point service is operated at Eastleigh and maintains schedules with Marseilles, Lisbon, Foynes and Alexandria. A teleprinter service links Eastleigh with Imperial Airways offices and the Meteorological Office at Hythe, and there is of course a teleprinter link to Portsmouth, etc. Departure and arrival messages and the usual route traffic are handled between Eastleigh and Marseilles, etc., and passed to the addressee via the appropriate teleprinter circuits. For the section of the routes from Marseilles to Rome, Athens, Alexandria, etc., route traffic messages are all handled by h.f. channels on a frequency of 11 200 kc./s.

All point-to-point stations throughout the Eastern routes collect and pass movement reports giving the arrivals, departures, delays, etc., of the traffic. The reports are collected at Alexandria and passed to Eastleigh every morning and evening; thus the movements of all aircraft can be tabulated each day.

Arrival, departure and meteorological messages are handled between Eastleigh and Foynes when aircraft are proceeding to and from Foynes on transatlantic flights via the northern routes.

At Foynes extensive provision has been made by the Eire Posts and Telegraphs for communications on the North Atlantic route. The corresponding station, provided and staffed by the Air Ministry, is at Newfoundland.

The Atlantic crossing represents one of the most difficult air routes and one of the longest sea crossings. Consequently an especially comprehensive communications system is necessary. Long-distance navigational assistance is necessary and hence high-frequency direction-finding, as well as medium-frequency, is provided.

The point-to-point service is carried out entirely by high frequencies, suitable frequencies being selected for regular operation according to time and season. The aircraft communication and navigation employs medium frequencies for the first and last 500 miles, and high frequencies for the longer distances, in order to overcome difficulties due to fading and skip distance which might necessitate continuous changes of frequency with increasing or decreasing distances.

Arrangements at Newfoundland

The station at Newfoundland airport operates with stations of similar characteristics at Shediac, Montreal and New York, in addition to Foynes.

Although the arrangements on sites naturally differ in detail, the layout at Newfoundland is in general representative of the provisions on this service.

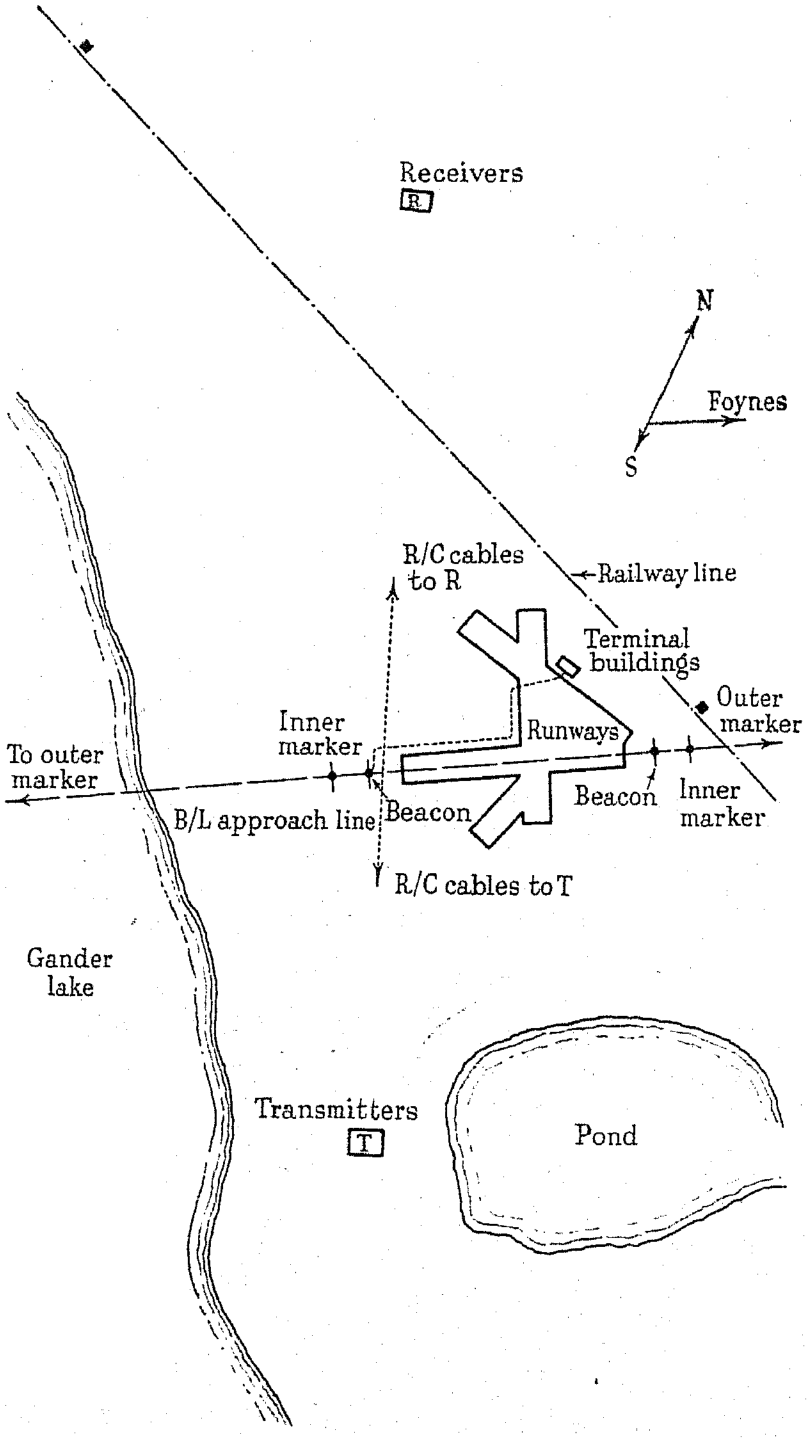

Fig. 19.—Layout of Newfoundland airport.

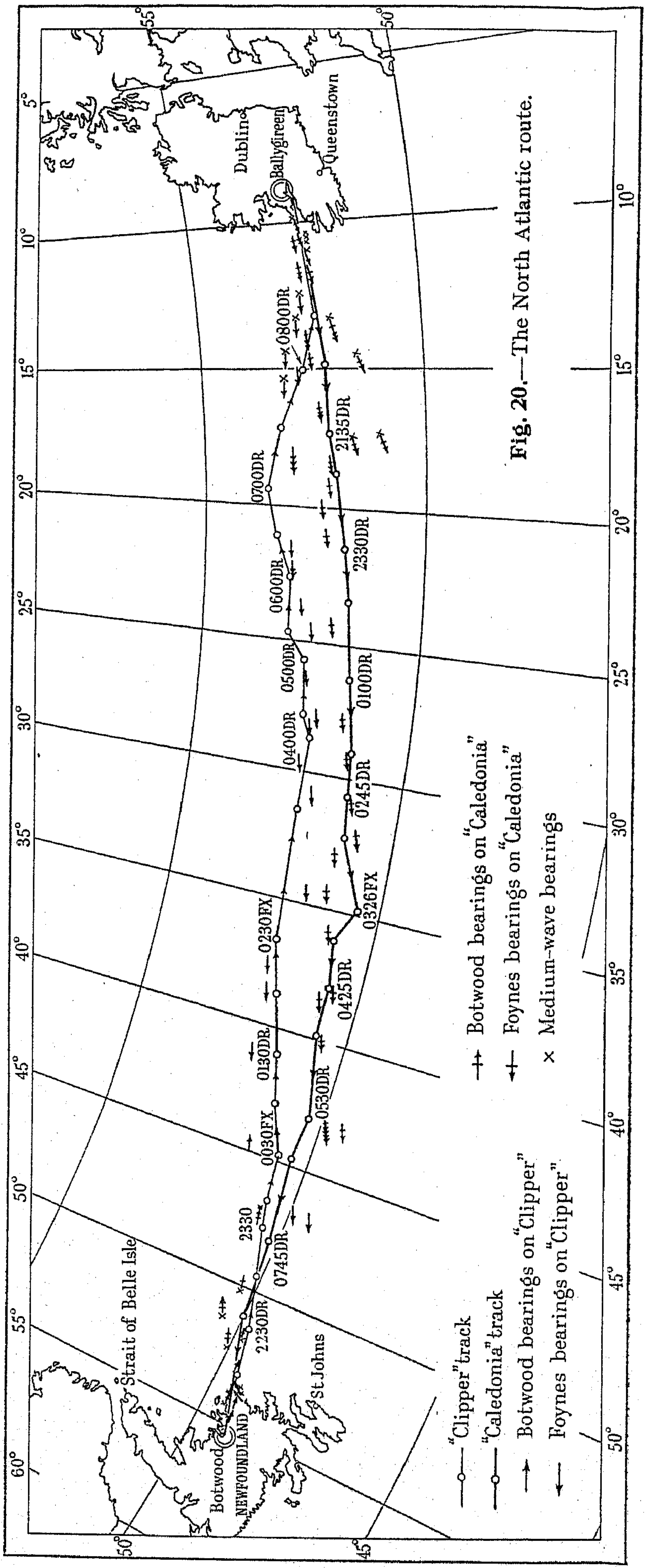

Fig. 20.—The North Atlantic route.

At the airport proper, which comprises the land aerodrome and its administrative buildings, is installed the following equipment for close-range communication with, and navigational assistance to, aircraft, for communication with similar equipment installed at the marine base at Botwood, and its alternative alighting place at Gander Lake, and for the reception of meteorological broadcast messages:—

(1) Intermediate- and medium-frequency low-power transmitters.

(2) Medium-frequency direction-finder.

(3) Intermediate- and medium-frequency receiver.

(4) High-frequency receiver.

(5) Medium- and low-frequency receiver.

(6) Ultra-high-frequency approach beacon.

At a point 2½ miles south of the aerodrome is the main transmitting station, containing:—

(1) A high-frequency transmitter exclusively for point-to-point communication with Foynes. Aerial power 3·5 kW maximum.

(2) Two high-frequency 4-channel transmitters used primarily for ground-to-air communication with east- and west-bound aircraft, one transmitter being used also for point-to-point communication with Montreal, etc.

(3) A medium-frequency transmitter for ground-to-air communication on 333 kc./s. up to ranges of some 500 miles. Aerial power 1 kW.

At a point 2½ miles north of the aerodrome is the main receiving station, containing:—

(1) Three high-frequency receivers.

(2) A medium-frequency Adcock D.F. receiver with remote aerial system.

(3) A high-frequency Adcock D.F. receiver.

A complete system of remote control connects the various transmitting and receiving points.

At Botwood there are installed:—

(1) An intermediate- and medium-frequency transmitter.

(2) A medium-frequency D.F. receiver.

(3) An intermediate- and medium-frequency receiver.

The aerials used comprise horizontal "rhombic," series phase, and normal non-directional T aerials.

At the Shannon Base the provisions are similar, with the exception that the two main sites comprise complete transmitting and receiving stations.

In Fig. 19 is shown the general layout plan of the Newfoundland airport.

So far, of course, no regular operations have taken place on the transatlantic route, and flights have been of an exploratory character in which the communication system has been put to test. At the same time regular routine communications have been taking place between the stations concerned. Excellent long-range communication has been obtained on the frequencies selected, and several exceptional medium-frequency communication ranges have been obtained and also D.F. bearings in excess of the 500 miles mentioned. These should, however, be regarded more or less as freak results.

The high-frequency D.F. results have been good, and in Fig. 20 is shown a chart of one of the flights of the Imperial Airways "Caledonia" and the Pan American "Clipper" on the 5th and 6th August, 1937. This was one of the early flights during which the high-frequency D.F. was being tried out.

An example of some of the bearings taken is given in Table 4.

Meteorological Information

Apart from radio-communication and navigation assistance, the transmission of meteorological information to aircraft is of paramount importance, particularly for long-distance routes such as the North Atlantic; hence the extensive arrangements made for the collection and dissemination of synoptic and regional meteorological reports, route forecasts, etc. These matters, however, come within the ambit of the meteorological authorities, and it is therefore only proposed to refer to one aspect of the conveying of meteorological information as this concerns long-distance routes and the aircraft equipment. On long-distance routes it is desired to be able to produce in the aircraft a weather map which will show the general trend over a fairly long section of the route.

Table 4

Bearing by dead reckoning	Bearing by high-frequency D.F.	Difference	Remarks
"Caledonia" outward journey, bearings from Foynes			
255°	265°	+ 10°	Left Foynes
259°	266°	+ 7°	
260°	259°	+ 1°	
263°	268°	+ 5°	
264°	268°	+ 4°	
267°	268°	+ 1°	
267°	268°	+ 1°	
267°	269°	+ 2°	
268°	271°	+ 3°	
268°	271°	+ 3°	
270°	271·5°	+ 1·5°	
271°	271·5°	+ 0·5°	
271·5°	271·5°	—	
272°	271·5°	– 0·5°	
272·5°	271·5°	– 1°	
273°	274°	+ 1°	
273°	274°	+ 1°	
273°	275°	+ 2°	
275°	275°	—	
275·5°	275·5°	—	
276°	276°	—	
276°	276°	—	
277°	275°	– 2°	
277°	276°	– 1°	
"Clipper" inward journey, bearings from Foynes			
280°	277°	– 3°	
280°	278·5°	– 1·5°	
279·5°	281·5°	+ 2°	
280°	280·5°	+ 0·5°	
280°	280·5°	+ 0·5°	
279°	277°	– 2°	
278°	276°	– 2°	
277°	277°	—	
276°	276°	—	
276°	275°	– 1°	
276°	276°	—	
277°	275°	– 2°	
278°	276°	– 2°	
277°	277°	—	
278°	277°	– 1°	
281°	276°	– 5°	
273°	273°	—	Arrived Foynes

To this end, experiments are being carried out in America to produce a "facsimile" equipment of reason-

*

able size and weight which will make possible the transmission of "facsimile" maps. One equipment has been produced, and in time to come this process may become general on large aircraft. At the moment, however, it is likely to add considerably to the weight of radio equipment carried.

In the meantime a system which has been found to be very satisfactory is used by K.L.M. on the Dutch East Indies route.

In this system the weather map is coded to give in convenient form points of longitude and latitude by means of which isobars and cold or warm fronts may be drawn on a map carried in the aircraft, these maps being small-scale versions of maps used for meteorological plottings.

The code system is as follows. In the first place a figure is chosen to indicate whether the longitude is east or west of Greenwich and north or south of the equator. Then follows the latitude and longitude, thus producing a 5-figure code. The following example will indicate the code system:—

29th January, 1939.

```
KF   35040   34439   34032   WF   34032
34021   34214   04503   OCC   04503   03907
KF   04503   04000   WF   04000   33501
KF   33501   03100   03010
995    GESLOTEN   04503   04508   04007   04205
1000   GESLOTEN   04500   04705   04411   04010
                  04002   04300   BOVENDIEN
1000   GESLOTEN   OM   33501
1005   GESLOTEN   34503   04905   04514   03812
       03505   03001   33206   33706   34003
1010   33014   33613   34110   34406   05000
       05105   04913   04217   03513   03007
1015   32919   33520   34021   34316   34510
       35005   05205   05316   06026
1020   33034   33525   34028   34425   34916
       35205   05409   05717   06223   BOVENDIEN
1020   34143   34236   34529   35225   35520
       35708   36112   36708
1025   06217   05811   05502   35803   36104
       36501
1030   GESLOTEN   OM   06307.
```

The group KF indicates a cold front, and following this are shown the points on which this front lies. The group WF indicates a warm front. Following this are millibars, viz. 995 followed by the 5-figure codes showing the points at which the pressure is 995 millibars.

The complete code therefore enables a map to be drawn showing fronts and isobars over a large area.

This coded message is transmitted on a high-frequency channel, and in the case of an aircraft on an inward service to Amsterdam from Java, for example, the coded groups for the Mediterranean are picked up when in the vicinity of Lydda. The radio officer then plots the map, a repetition of the message enables any necessary corrections to be made, and of course subsequent transmissions enable changes to be recorded. In this manner the general trend of the meteorological conditions can be observed and the route and height of flight arranged accordingly.

It might be thought that this system would involve a considerable amount of communication; but the information conveyed by the number of groups shown is quite considerable, and, allowing for the transmission to take place at a speed of 17–18 groups per minute, the time taken to receive the message is only 6 minutes, while the actual drawing of the map need only occupy a further 5 minutes. It is open to argument whether a facsimile system would show any material advantage, even perhaps without considering the pros and cons of the additional weight, size, and power required.

In Fig. 21 is shown a typical map drawn from the coded data given.

(5) A BRIEF OUTLINE OF THE COMMUNICATION SYSTEM IN THE U.S.A.

The fundamental difference between the European and American systems of communication is of course that the American system is national and not international in character.

The main features of the American system are:—

(1) An extensive use of equi-signal track beacons operating on frequencies in the band of 200–400 kc./s. and ranging in power from about 100 to 500 watts. With these beacons are employed medium-frequency and also v.h.f. marker beacons.

(2) In general there is no system of direction-finding at the airports. The aircraft may carry D.F. equipment and may use it in conjunction with the equi-signal beacon or other suitable station for navigational purposes, but it is not possible for the airport staff to take any D.F. bearings on the aircraft or to ascertain its position except by reports made by the pilot. There are exceptions in the form of a D.F. system on frequencies of the order of 1 500 kc./s. at coastal points for oversea routes.

(3) Position reports are made very regularly by the pilot and, in general, telephony is used. These reports are more frequent than in Europe. The frequencies employed are mainly in the high-frequency bands.

(4) In connection with (3) it is general practice for individual operating companies to run their own ground stations at the main airports.

(5) A telephone channel is often provided in conjunction with the equi-signal beacons for the broadcasting of meteorological messages and weather reports. These broadcasts are very frequent and constitute the bulk of communication to the aircraft from the ground.

(6) Air-traffic control is performed over a rather more limited area than in Europe and the staff depend on the radio stations owned and operated by the individual companies for information on aircraft movements, but in proximity to airports a separate traffic-control channel is provided so that the traffic staff may direct the aircraft as desired.

(7) Radio-telephony is extensively employed on h.f. channels and the equipment is operated by the pilot. Telegraphic operation with a radio officer on board is limited mainly to long-distance routes and to operation on routes to South America, etc.

A teleprinter system interconnects the airports and is used in a similar manner to the European system, although the procedure, codes and layout of messages are different.

High-frequency route traffic channels are also employed and are generally provided, staffed and operated by individual companies.

This, combined with the operation by individual companies of their own ground-to-air h.f. communication channels, is leading, as can well be imagined, to the creation of rather difficult situations at some airports where there may be several independent radio stations on closely adjacent frequencies, and as a result there is now a tendency towards an amalgamation of interests in the communication field, with the Federal communication authorities.

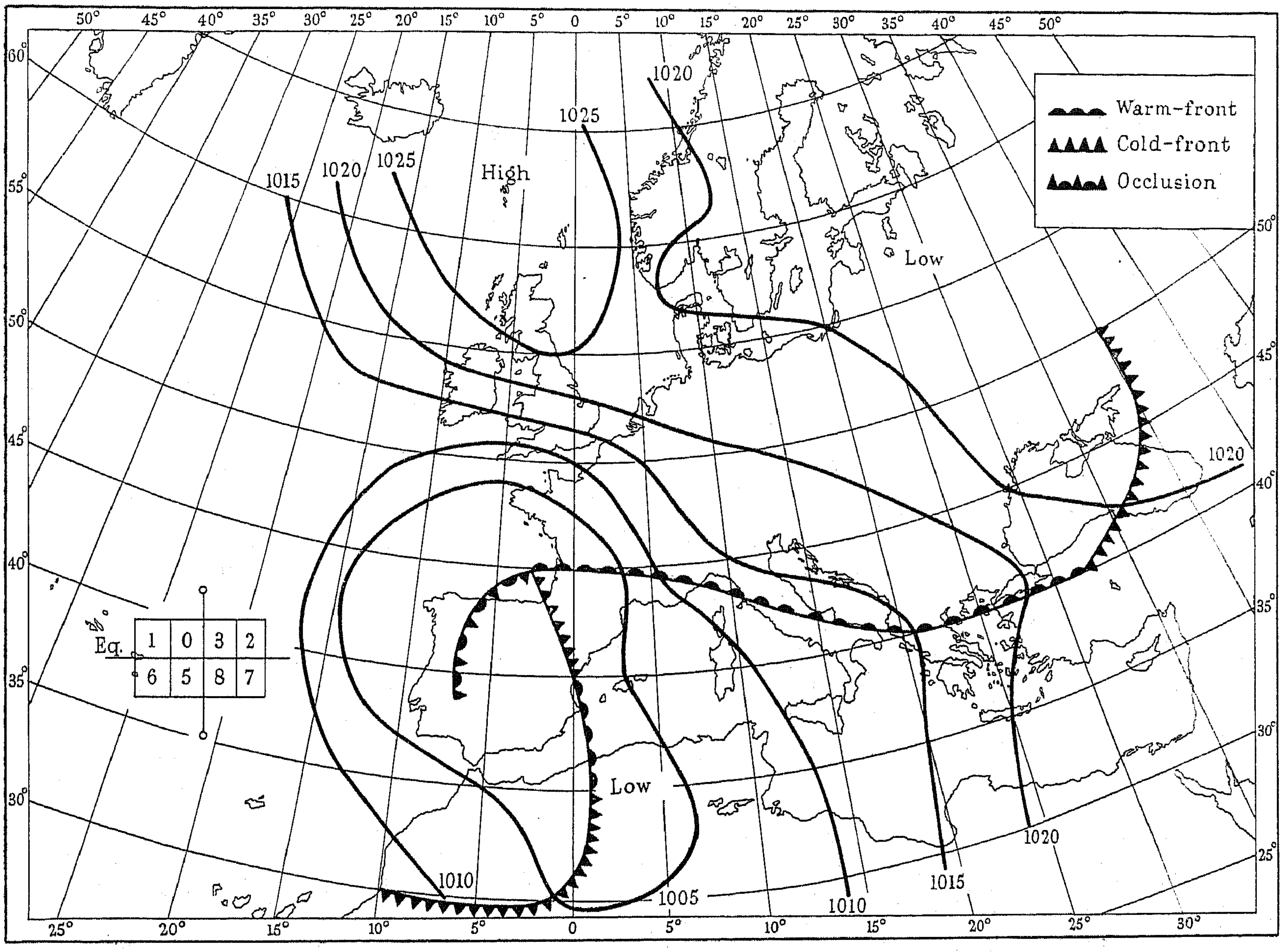

Fig. 21.—Meteorological map drawn from coded transmissions.

Another outstanding difference concerns the collection and dissemination of meteorological reports throughout the entire air routes. Whereas in Europe we have a system of radio broadcasts in code of regional and synoptic reports, in the U.S.A. all reports are handled by the teleprinter system.

The tempo of developments in the U.S.A. is much faster than in Europe, and again the national aspect is an asset. Furthermore, the size of the country and the very large markets available have created a correspondingly large number and variety of equipments for aircraft, with very keen competition between the various companies. In this direction greater attention has been paid to the design of receivers and D.F. equipment for aircraft than in this country and, as has already been mentioned, the modern forms of aircraft D.F., both aural and visual, were originated in the U.S.A.

To the U.S.A. also is due efficient engine ignition shielding, efficient engine-driven power units, precipitation and induced-static elimination, and many other developments. It may also be said that the aircraft radio installation is regarded more as a part of the aircraft as a whole than in England, and as a result the application is better and in many respects the technique and execution of the individual parts of the installation are better.

On the larger aircraft a great deal of attention is being given to the problems of 110-volt a.c. power supply, and perhaps high-voltage a.c. or d.c. power supply may one day spread into general use. The use of track beacons has of course resulted in extensive development of blind-landing aids, and there are a greater variety of systems under test than in Europe.

It is not easy to draw direct comparisons between the U.S.A. and European systems or to enlarge on the advantages or disadvantages, owing to the fact that one system is, as already mentioned, essentially national and the other international. On the whole a system of direction-finding such as the European has advantages which have already been mentioned and which may well outweigh the additional communication caused and thus on the whole be more useful than a track beacon system.

Developments are now taking place in the U.S.A. in the direction of the use of u.h.f. track beacons in the band of frequencies between 60 and 66 Mc./s., and also the use of 129 Mc./s. for radio-telephone airport traffic-control channels. Frequencies of 60–66 Mc./s. are also being used for a point-to-point radio teletype service, and as high as 750 Mc./s. for glide-path experiments employing horn radiators.

In addition to the u.h.f. track beacons, Adcock-type D.F. installations are being applied to the overland routes. These equipments are, it is understood, provided with remote-reading indicators employing cathode-ray tubes, and it appears that a combination of D.F. and track beacons is ultimately intended.

Attention is being directed towards sub-stratosphere flying and the performance of navigational aids at these heights, and, in view of the prevalence of radiotelephony, consideration is being given to the application of frequency modulation to aircraft equipments.

(6) FUTURE DEVELOPMENTS

Developments are taking place which will in due course do much to improve operations in bad visibility and poor weather conditions generally, and to alleviate congestion of traffic, etc. Communication development and organization alone, however, cannot solve certain fundamental difficulties which, for one example, come about by virtue of the fact that it has not so far proved possible as a general procedure so to arrange departures from one airport for another, known to be in an area of poor visibility, that arrivals will not tend to bunch together. Furthermore, one must consider whether the tendency towards a service operating on the principle " On the hour every hour " regardless of load is not making an impossible demand on the communication system. An empty aircraft needs just as much communication as a full one, and it should be kept in mind that on a short route with fast aircraft the time taken to land during bad visibility becomes the governing factor.

Developments may be classified broadly into two groups, namely immediate improvements and future application of newly developed navigational aids.

Some improvement is being effected by the immediate application of the additional frequencies obtained at the Cairo Conference to additional channels for zone and area communications, while the lines on which new developments are taking place are as follows:—

(1) Equi-signal track beacons on frequencies of the order of 33–38 Mc./s., and even higher.

(2) Improvements in blind-approach and landing systems, including a true glide path.

(3) Development of an absolute altimeter.

(4) High-frequency direction-finding.

(5) Devices for providing warning of collision.

(6) Homing devices on frequencies of the order of 33–38 Mc./s.

(7) Direction-finding (free from polarization errors) for use on aircraft.

(8) The coupling of a blind-approach and landing system with an automatic-pilot equipment.

(9) The coupling of homing devices with automatic pilot.

(10) Balloon meteorological sounding.

With regard to (9), this is now an accomplished fact, but so far as the author is aware the system has not been used on passenger transport aircraft.

Considerable work has been carried out in the U.S.A. and in Germany on the use of very high frequencies for equi-signal beacons. Tests have also been made in Australia, where a 33-Mc./s. track beacon is in use. The aerial system comprises two synchronously switched reflectors and one radiator after the manner of the landing and approach system, erected on a tower 30 metres high. An aerial power of 0·5 kW is used and produces ranges of 160 km. at 2 000 to 3 000 metres, although the receivers employed have a sensitivity of the order of 300 μV/m. Experiments made in the U.S.A. on frequencies in the 60–66 Mc./s. band have been very successful, and both vertically and horizontally polarized 4-course equi-signal track beacons have been tried. As a result it is anticipated that in due course most of the existing medium-frequency beacons will be replaced by these u.h.f. beacons. The advantages are freedom from static, freedom from reflection from the ionosphere, more economical aerial system, and less space required, also the possibility of placing a larger number of stations in a given frequency band.

Beacons of this nature may find application in the European system, but still there must be kept in mind the relative merits of a system whereby aircraft can be located from the airport as distinct from a system which, while enabling aircraft to fly on a given track, does not enable positions to be obtained except by reports from the pilot.

Time does not permit going into detail on the subject of the numerous forms of blind-landing systems which are being developed. The principles are in general similar and consist of horizontal guidance, glide path and position markers. These requirements are provided singly in some equipments, and combined in others, but as the requirements of the glide path are not easily combined with those of the horizontal guidance the best system may ultimately be one employing a separate glide-path transmitter. In this direction some work has been done on the subject of horizontally polarized radiation from conductors below surface-level. It should be considered whether horizontal guidance plus an absolute altimeter will not ultimately provide a better solution than the radiation of a glide path.

A very promising development in the form of horn radiators employing the principles of radiation from hollow conductors is now taking place and is described in the *Proceedings of the Institute of Radio Engineers* for December, 1938, and January, 1939. The highly directional and easily controllable radiation patterns produced have much to recommend them for use in blind-landing systems, and also for localizing beacons for warnings, landmarks, etc.

Whether or not a blind-landing system will be successfully coupled with some form of automatic pilot for a completely automatic landing remains to be seen.

Some results of high-frequency direction-finding on the Atlantic route have already been given. The development of various forms of equipment, including the use of cathode-ray tubes in a direct-reading direction-finding equipment, will no doubt shortly enable a reliable service to be given. High-frequency direction-finding employing cathode-ray tubes may find very useful application on long-distance routes, and the principles applied to medium-frequency direction-finding would give a useful increase in speed of operation on local zone channels. Whether or not medium-frequency direction-finding channels of this type would be a worth-while development depends on the progress made in the use of u.h.f. approach and landing systems.

One problem for which the increased speed of operation mentioned above would be advantageous is that of providing for the traffic personnel the maximum amount of information of the position and height of aircraft on a crowded route with the minimum of communication. Alternatively, the provision of a device to indicate the proximity of one aircraft to another has been suggested. Such a device must give not only a warning of proximity but should also give direction and relative altitude, otherwise the warnings will have an effect which is probably worse than no warning at all. In connection with devices of this type and also in connection with such items as u.h.f. homing devices, one must consider that there is a limit to the amount of equipment which can be efficiently employed in the aircraft. Stated generally, there are two extremes; one a complication of equipment in the aircraft in attempting a measure of "self sufficiency," and the other a concentration of ground equipment with inadequate provisions on the aircraft. Between these two lies an economic ideal. In the author's opinion reliable two-way communication, homing and direction-finding, u.h.f. landing and track beacon, and an absolute altimeter, should be the maximum complement of equipment. Indiscriminate flying can never be sorted out merely by the application of instruments to the aircraft.

One of the most valuable instruments will undoubtedly be the absolute altimeter or terrain clearance indicator. A great deal of thought and ingenuity has been expended on this problem, and the solution has been materially aided by the development of more reliable methods of generating adequate energy at frequencies of 300 to 900 Mc./s. Successful experiments have been carried out in the U.S.A., and it is understood that satisfactory flight tests have been made. The system used operates on the interference produced between direct and reflected rays of a frequency-modulated radiation on frequencies of the order of 300 to 900 Mc./s. and higher.* A horizontal dipole is used for radiation, and the height indicated is the vertical distance directly below the aircraft. Operation up to 5 000 ft. is provided with an accuracy of 9–10 %. It would appear to be desirable for the radiation diagram to be such that the distance indicated is ahead of the aircraft, so indicating the approach of high ground, etc.

The trend of development in general is towards the use of higher and higher frequencies, and with the growth of long-distance high-altitude routes the general communication system may tend to divide into two groups, one dealing with relatively short distances covered at the altitudes now general, and the other dealing specially with sub-stratosphere flying on long-distance non-stop routes. For the latter u.h.f. track beacons may be very advantageous in view of the greater range at high altitudes.

In connection with all long-distance flights, and especially sub-stratosphere flying, upper atmospheric conditions and the forecasting of ice formation are of great importance, and thus the meteorological sounding balloons employing high-frequency and ultra-high-frequency transmitters arranged to give information on the temperature, humidity, etc., are playing an increasingly important part in the development of commercial air routes.

The application of equipment and channels operating on high frequencies depends on the ability of the aircraft to carry the necessary u.h.f. reception equipment capable of giving a good service. This again involves considerations of screening of ignition system, weight, space, installation accommodation, correct layout, etc., and until the installation of high-frequency equipment becomes general and is allowed for in the arrangement of aircraft accommodation, it will be difficult to proceed with the application of developments employing the u.h.f. spectrum, at anything like the speed which is desirable.

CONCLUSION

The author has attempted to present a reasonably comprehensive view of the civil aviation communication system as a whole, the service rendered, and the lines on which developments might proceed. Consideration in detail of various items has had to be avoided.

This paper was prepared prior to the outbreak of the difficult conditions under which we are now placed, and describes the communication arrangements operating during peace time. Whether at the end of hostilities civil air transport routes and communications will bear any relation to the past cannot be forecast; possibly a rate of progress even greater than has taken place since 1918 may occur.

Perhaps we may look forward to types of aircraft planned to facilitate application of radio communication and navigational aids. By the use of moulded plastics we may even see aircraft produced with an insulated section enabling the fuselage to be used as a radiating system.

Acknowledgments

The author would like to express his thanks to the Air Ministry for permission to publish the paper, and to the following for information and illustrations supplied: Standard Telephones and Cables; Radio Transmission Equipments, Ltd.; Marconi's Wireless Telegraph Co., Ltd.; Philips Transmitting Division, Eindhoven, Holland.

He would also like to thank Pan American Airways for the photograph showing the installation in the Boeing 314 flying boat, and Mr. W. A. Thorn for his kind assistance in checking the MS.

[The discussion on this paper will be found on page 344.]

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* *Bell System Technical Journal*, 1939, **18**, p. 222.

DISCUSSION BEFORE THE WIRELESS SECTION, 1ST MAY, 1940

Mr. W. L. McPherson: In the opening sentence of his paper* the author makes a remark which is perhaps a little exaggerated, for he implies that the commencement of the real development of radio-communication occurred at about the same time as the development of aviation transport. His statement rather ignores the fact that at the time of the birth of civil aviation the marine application of radio was already well established, so much so that in the war of 1914–18 it was made compulsory for all passenger ships and all vessels of over 1 600 tons to carry radio. Marine radio practice had in fact a considerable influence on the development of aviation radio practice.

It is interesting to compare the relative weight of the two applications, taking as a basis the number of stations registered at the Berne Bureau in 1937, which is the latest date for which I have figures. The number of marine mobile stations at that time was 17 348, while the number of registered aircraft stations was 3 369. It seems, therefore, that the marine interests are still very much larger than the aviation, although it must be admitted that the aviation figure is increasing very rapidly. If the 1937 figures are taken, there is a ratio of approximately 1 : 5 as between aviation and marine, and it might be expected that the needs of the two services would have been met by corresponding frequency allocations. Actually, after the Cairo Conference the marine services were allocated the exclusive use of frequency bands covering 885 kc./s., while the aviation interests, with only one-fifth the number of stations, were allowed 975 kc./s. (including the medium and short wave-bands). They were also allowed another 16 500-kc./s. band width in the ultra-short wave-band. I do not think, therefore, that the aviation interests are really justified in complaining about shortage of channels, although this is hinted at in the paper.

Possibly the list of airport requirements referred to in Section (1)B, on page 317, is responsible for what shortage may exist. There seems to me to be no excuse for using radio for communication between airports when a good land-line system is available. The use of radio for communication to mobile stations, where radio is the only possible means of communication, is so important that radio should not be used except for communication between and to and from these mobile stations and for broadcasting, unless there is a strong economic or strategic argument for the use of radio in place of land-lines. Certainly in Europe in normal times there would seem to be no excuse for radio inter-airport work. In the paper there are various references to teleprinter working which indicate that the situation is gradually changing.

The author does not mention the existence of regulations with regard to the compulsory equipment of aircraft with radio, but such regulations do exist. On the marine side in recent years there has been a notable tendency to fit radio on ships, whether or not it is compulsory under the regulations affecting them, and I should like to ask whether a similar situation applies in regard to aviation.

No mention is made in the paper of public correspondence services between ground and aircraft. I believe that at one time the French administration, at any rate, would accept telegrams for delivery to a passenger in a cross-Channel aircraft. Has this service been entirely dropped? There does not seem to be much need for it on the short Continental "hops" of about 2 hours, but possibly on the long-distance transatlantic flights there may be some call for it.

With reference to Table 3, I notice that the figures for power and terminal voltage are given in terms of an aerial of 200 $\mu\mu$F capacitance and a total circuit resistance of 10 ohms. Both these figures seem to me to be rather low for a trailing aerial, and the capacitance figure is rather high for a fixed aerial. Perhaps the author will say just how far he considers them to be representative of the extremes which we may expect.

In dealing with transmitters the author makes use of the term "metre-amperes," which shows the influence of marine practice. It is a great pity that the use of this term should be continued, because "metre-ampere" can signify anything. It would be preferable to adopt the figure of millivolts per metre per unit power input: the case of an aerial having an effective height equal to twice its own height would then not arise.

In Table 2 the author gives sensitivity figures for an Adcock system of about 3 μV/m., using masts 75 ft. high. It is worth while noting that the same figure has been obtained on a semi-portable Adcock system using masts only 45 ft. in height, and with these lower masts it would be possible to put the Adcock equipment much closer to the aerodrome, which might have some advantages.

Turning to the question of landing devices, the author takes up the point of the permissible intensity of false courses, and the figures he gives indicate that at 12 miles the field strength is 20 db. greater than at 15 miles. This seems an extraordinary attenuation for such a relatively short percentage increase in distance, and I should be glad to know how he arrives at it. On comparing these figures with the C.C.I.R. propagation curves for 10 metres, taking one station at ground-level and one at 500 metres, we find that the total attenuation between 15 miles and 2·8 miles is between 30 and 35 db., instead of 80 db. This does not influence the point that the author is making, but it is a very big difference when put in terms of beacon requirements.

Still in connection with the use of landing devices, the author makes no statement about the polarization used. Most of the European landing equipments make use of vertical polarization, but there has been considerable evidence in the last few years to show that horizontal polarization is preferable, as it reduces the effects of reflection from such things as hangars, and also variations due to changes in the conductivity of the ground over which the beam is transmitted, caused by the presence of roadways. The figure of 33 Mc./s. was originally chosen with the idea that it would give immunity from interference between aerodromes, but actually that has not been the case, and in some instances there has been very severe interference. For example, a beacon situated in Australia has been found to give quite an appreciable signal to aircraft trying to land in South

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* Revised for the *Journal*.

Africa. In view of this interference, there seems no doubt that the American tendency—perhaps it is more than a tendency—to employ much shorter wavelengths is well justified.

Referring to Plate 2, perhaps the author has been a little unfair to British aircraft radio practice in not explaining in the caption what each of the two illustrations includes. Fig. 17 presumably shows the transmitters and receivers together, whereas Fig. 18 is confined to the receiver, the transmitter being tucked away in the odd corners to which the author refers.

Mr. W. K. Brasher: For some 10 years I was connected with air transport communication services in the East and I think this paper should be of assistance to the local engineer or the technical adviser in obtaining appreciation of the needs of the rapidly growing air services, particularly where rather dangerous "hops" are being served.

On eastern routes, particularly at centres where a number of interconnected air lines and shuttle services meet, inter-airport traffic tends to become relatively denser than in Europe, and at the same time increased attention has to be given to aircraft travelling over, say, 500 miles of desert on which there are almost no landmarks and where dust storms occur in which blind flying may continue for 2 hours or more; it then becomes all the more essential that steps should be taken to remove all unnecessary traffic from mobile frequency bands. The author deals with this on page 318, and in my experience the tendency of administrations to continue working on a mobile band until congestion actually arises and reaches a dangerous point is aggravated by a tendency for airport officials and the operating company's staff to forget that there are complementary land-line channels. When a by-product circuit requiring little maintenance can be provided at very little expense to give a teleprinter service between airports, there is no excuse for cluttering up the ether with unnecessary inter-airport wireless services. The utmost pressure should be exerted by officials abroad in an endeavour to secure the co-operation of adjacent local authorities in substituting physical links for wireless links.

There is a further point in connection with the congestion on 333 kc./s. I believe that a few years ago the International Commission for Air Navigation issued recommendations allocating the aircraft frequencies of 346 kc./s. and 350 kc./s. in accordance with the class of the aircraft, and I hope that these recommendations have not been abandoned. I know that there are difficulties in getting aircraft to adhere to restricted frequency-bands, but in order to reduce the congestion on 333 kc./s. and to reserve this frequency for its most important function, a measure of sub-division would be desirable.

Under the particular conditions on eastern routes it is essential that economy in planning shall be combined with economy in maintenance and administration. I believe that one of the chief factors in the plans for night flying which would have been put into operation on many distant routes if it had not been for the war, was the improvement obtained in aids to navigation through the accuracy of the Adcock system, but the difficulties in a small administration arising through the duplication of staff, plant and buildings, tend to delay the installation of a desirable system. Fig. 6 gives a plan of a very excellent D.F. building, but I would ask why there is any necessity for this building at all except in situations where special circumstances arise.

I have recently been connected with the installation of an Adcock receiver at a new airport which I can best describe by reference to Fig. 19. It is usual nowadays, even if there are not permanent runways, to plan definite landing paths, and a not unusual arrangement is shown in that Figure. There are a number of cases in which the Adcock masts can be so disposed that they form no more obstruction than the terminal building itself, and they can be sited sufficiently clear of the building and the hangars to be free from undesirable effects. In the case I have in mind the Adcock masts were placed 250 metres from the control tower, and calculations had shown that there would possibly be a loss of 4 db. in the cable and the matching equipment, but I am certain that the actual loss was lower, and the results obtained were excellent in every way.

As it may assist others similarly placed, I will describe an experience in connection with the Palestine civil aviation transmitters, which were concentrated for economy in operation at a point chosen with the object of obtaining good radiation and where there were already a 20-kW broadcast transmitter, a coast station and a police transmitter. The site is some 35 km. from the receiving station, and the two are within optical range. There are three alternative land-line routes, and these provide more than an adequate factor of safety in ordinary times; but, when excessive sabotage broke out, the claims of military and public services for immediate re-routing conflicted with the demand for the re-routing of the control lines over the few remaining circuits. We therefore installed at the receiving station a small 7-metre transmitter, care being taken to choose the frequency and the aerial position so that there was no interference with the receivers. A u.h.f. receiver was installed at the transmitting station almost underneath the 20-kW aerial, and here again the choice of frequency was important. We modulated the 7-metre carrier firstly by 6 channels of a 12-channel voice-frequency telegraph equipment which was used for the normal control circuits, 6 channels (3 keying circuits and 3 start-stop circuits) being sufficient for emergency purposes. Secondly we modulated the transmitter again with the 5 000-cycle carrier of a standard Post Office single-channel carrier circuit, and this channel was used by the operator in the receiving station to announce his requirements as to wave-changes, etc., on a loudspeaker which was preceded by an independent amplifier inserted after the filter and demodulation circuits. In a period of about 6 months during which the link came under my observation, there was not one case of interruption to aircraft services through the failure of this u.h.f. system, which was operated continuously when the restoration of sabotaged lines was being carried out.

Table 4 gives an interesting comparison between bearings by dead reckoning and those by h.f. direction-finding. I have taken similar records over land, and I think it would add to the value of the Table if the author would include the distance of the aircraft from the receiver when each of these bearings was taken.

Group-Captain D. H. de Burgh: As regards the author's suggestion of having a combined m.f. and h.f. transmitter, I am not so sure that it would not be wiser to use separate sets. In connection with aircraft installations generally, I do want to put forward a plea for standardization, which I think would make the whole problem very much easier. If there were some degree of standardization of sizes and shapes, any new device could be readily and relatively easily introduced. In that connection we at Farnborough had some discussions with Marconi's Wireless Telegraph Co. and Standard Telephones and Cables, Ltd., and we discovered that the conclusions we had come to as to desirable sizes and shapes were almost identical, which proves that we were all thinking very much along the same lines, although from different points of view.

The author makes a plea for a power supply of the order of 100 volts; but a recent paper in one of the American technical journals, in which this question was analysed very carefully, seemed to indicate that there was no material gain in exceeding 24 volts. I should like to have the author's comments on this view. He refers to an 800-cycle power supply, and while I have had no experience of such a supply, I wonder whether it would not lead to difficulties with regard to interference in communication circuits, and whether it would not be worth while to choose 400 c./s. and pay the price of the greater weight.

With reference to the suppressor developed in the U.S.A. for dealing with static interference, I presume the author has in mind the trailing-wire scheme. Is such a device necessary in European countries?

Finally, the author seems to me to be somewhat biased in favour of American practice. I am inclined to think that the reason why America is possibly ahead of us in this respect is that the Americans—particularly the operating companies—are more communication-minded than the British. I think that until comparatively recently the operating companies in this country looked upon wireless communication as a necessary evil, and did not welcome it.

Mr. P. H. Spagnoletti: I should like to put forward yet another reason why radio circuits should not be used for carrying messages between airports. Figures which I saw on the subject of communications in the United States showed that the cost of running wired circuits over land was about one-fifth that of running radio circuits.

The author raises the question of the frequency stability of transmitters in the air, and points out the difficulties attendant upon the transmitter being off frequency. It seems to me rather difficult to understand why the ground stations, which can have more elaborate precautions for obtaining the requisite stability, should be crystal-controlled whereas the aircraft stations, in which it would be difficult to provide such facilities on account of weight restrictions, are generally not crystal-controlled.

The author covers the point of direction-finding on aircraft quite adequately, but he gives too little attention to the future in that he does not emphasize some of the advantages of the radio-compass type of instrument. A visual direction-finder has an advantage over the aural type in that when the plane is swinging off its course some indication of this fact is given by the movement of the needle, but the amount of the swing is not indicated. In the case of a radio compass, however, the amount of swing is indicated, and, further, if this radio compass is combined with a repeater scale from a gyro or magnetic compass, then reading the coincidence of these scales will give the operator the bearing in which he is interested—that is, the magnetic bearing of the station—independently of the behaviour of the aircraft itself.

The American system has suffered from certain disadvantages, particularly, as most people know, that of false courses given by medium-wave beacons. The Americans seem to get over some of their difficulties on the aircraft equipment by the use of short-wave communication channels rather than medium-wave; very few aircraft in America have to carry a long-wave transmitter with a trailing aerial and its attendant difficulty of high voltages.

In connection with the altimeter mentioned in col. 1, page 343, although the theoretical inaccuracies are of the order of 9–10 %, in point of fact the errors during operation have proved to be rather lower. For periods of 2 months, when the instrument was properly adjusted initially, the worst errors were, as far as could be checked, 2 %. The error of this type of instrument is a percentage one, and from this point of view such an altimeter has an advantage over the barometric type, which has a constant error. Where accuracy is most needed, i.e. near the ground, the inaccuracy of the barometric type of altimeter increases relatively to that of the radio type. Another point is that the radio altimeter does not indicate the distance directly under the aircraft but, by virtue of its circuits, the distance to the nearest terrain.

Mr. J. E. Rhys-Jones: The paper indicates that we have lagged a little behind America in regard to air transport communication, because our communication service grew up to meet the requirements and the growth of the transport service, and it seems to me that the Air Ministry has taken a bold step now in reorganizing it and putting it on its feet.

I am interested to see whether the tendency is to have separate units for each function or to use a composite apparatus, in which one receiver covers all the frequency bands required and is also used for D.F., homing, etc. A composite unit has the advantage of smaller size and weight, but separate units are more reliable and give better service.

The author does not mention routine measurements and the attention that receivers should periodically receive. (I refer to receivers because transmitters generally show up their faults in the meters situated on them.) The limiting factor is noise in all reception circumstances, and I should like to know whether any work has been done in this country, as I believe it has in America, on the normal reception channels, by fitting larger-size or more efficient and preferably directional aerials. This could enable the power in the aircraft transmitter to be cut somewhat.

With regard to the high-frequency power supply, I believe one of the difficulties is that the starting torque is very low with high-frequency motors, and a great deal of the auxiliary apparatus in aeroplanes has to be driven from the electricity supply. This difficulty could be overcome by the use of separate generators or rectifier units, but only at the cost of an increase in weight.

There is one point with regard to altimeters which is not generally known, and that is that reflection systems are reported to have been in use in Germany for some time. Such systems have been on test on their aircraft, but were abandoned because they were found to be unreliable. The reported difficulty is that the apparent surface of the earth from which the wave is reflected may be up to 50 ft. above or below where the surface of the earth really is. This is especially so over wet tarmac.

Mr. C. J. Gill: The part of the paper in which I am principally interested, Section (4), is unfortunately the shortest. While the incidence of stations and services on the Empire routes is not so great as in the case of Europe, the importance of these services, having regard to length of "hop," terrain flown over and sparseness of landing grounds, renders the communication services of such vital importance that they should have merited more detailed treatment. Problems are very different from those in Europe, and I should like to add to Mr. Brasher's comments on the difficulties of operation of radio-communication services for the air in small administrations abroad. I have for the past few years been endeavouring to administer such services at one of the focal points of Empire and other international air services in the Near East, where, in common with other administrations, the need for some of the more involved and expensive radio services is not appreciated by the people who have to put down the money to provide them. In general, the countries concerned do not operate international air lines and consequently get no such reciprocal advantages as are obtained by countries in Europe. I feel that the less these administrations are called upon to provide in the way of complicated radio services, the better the primary essentials will be provided and staffed.

One of the principal difficulties is in connection with the provision of Adcock D.F. receivers in isolated locations, e.g. in intermediate aerodromes, which are often only refuelling points. The expense of installing an Adcock system on a site remote from the aerodrome control tower and of staffing it there and also staffing a land-line into the control tower does tend to render the Adcock a very difficult proposition. The alternative, and generally the only practicable method, that of locating the Adcock control in the control tower of the aerodrome and using a remotely controlled system, means blocking up a considerable portion of the periphery of the aerodrome from a flying point of view and may have serious effects on accuracy, particularly as ground conditions in the vicinity of the aerodrome—that is to say, the continuity of electrical earth conditions—are not always good. In fact, the technical and staffing difficulties involved and the doubtful accuracy obtained in such cases, together with the infrequent use made of D.F. facilities already established in similar conditions, make one wonder whether the expense involved is really worth while. The fact that in most cases the absence of land-line interconnection between such D.F. stations makes it impossible for "fixes" to be obtained with any rapidity or usefulness is another argument against Adcock operation in remote locations.

The burning question of land-lines versus radio services has had a great deal of attention in the Eastern Mediterranean, where, unfortunately, land-line services are largely non-existent and there is either desert or water separating the countries concerned. Until 2 years ago, conditions in the Eastern Mediterranean were almost chaotic; up to a dozen ground stations were working on 900 metres (point-to-point as well as ground-to-air), with the result that the chance of an aircraft getting through at once was almost negligible. That has since been rectified, on the initiative of the Egyptian Administration, by the introduction of short-wave services on a time-schedule basis; a system which has much to commend it in the way of saving in staff and equipment, but which is unfortunately very difficult to organize on an international basis.

I am sorry that the paper contains no reference to the necessity of supplementing the efficient technical arrangements made in ground and aircraft stations with precise instructions to the operators of those stations. Procedure is inclined to vary throughout the world, and we had a great deal of difficulty until we issued a comprehensive set of regulations to both ground operators and aircraft operators flying through the country and compelled them to use the method of operations laid down in these regulations. The importance of adherence to the instructions by operators in order to ensure the most efficient use of the communication services provided, and particularly in connection with distress procedure, cannot be over-emphasized.

Lieut. W. A. Duncan (*communicated*): The paper furnishes a clear picture of the standard European ground organization, an organization conceived originally on a basis of aircraft traffic of relatively low density. Whether this type of organization has not certain intrinsic limitations which render it incapable of keeping pace with a progressive growth of air transport services is a matter for consideration. Even in existing circumstances, communications tend to become unequal to the load thrown upon them at major airports during periods of bad visibility.

As the author indicates, the function of the ground direction-finding organization has become twofold. To its original role of furnishing navigational assistance and transmitting meteorological information to pilots in flight there has been added the duty of keeping the air traffic control staff at the aerodrome continuously supplied with details of the position and movements of every aircraft, and of maintaining constant contact with all aircraft so that advice designed to minimize the danger of collision can be passed to them instantaneously.

Both navigational and control services are, under the present system, carried out on the same frequency channels by cumbersome methods of "question and answer," and are conditioned by the limitation of speed inherent in any form of two-way communication. Moreover, the demands of the collision-prevention service grow in proportion to the density of aircraft movements, and are liable to crowd out the navigational service. This in turn causes the aircraft to "queue up" whilst waiting to obtain D.F. assistance; the risk of collision is thereby increased and, with it, the volume of warning communications necessary; the waiting aircraft require still more D.F. assistance to enable them to keep station: thus a vicious circle tends to be created and communications become congested.

To a certain extent the situation can be relieved by the provision of additional channels (assuming the frequencies are available), but this involves separating the aircraft into groups operating on different frequencies, and for air traffic control purposes the information concerning the movements of one group of aircraft has laboriously to be collected by the ground station and passed to the other groups on their respective frequencies. The whole process is then liable to become too slow to compete with the speeds of modern aircraft, and is, in addition, prodigal of wavelengths and expensive in staff. Already the numbers of ground wireless-telegraph operating staff and control staff seem disproportionate to the number of aircraft to be served.

It is only along the lines of rendering the aeroplane far more self-dependent than it is at present that a way out of the existing cul-de-sac can be foreseen. Some progress has already been made in this direction so far as navigational assistance is concerned; for example, when loops are carried, any number of aircraft can take bearings on a single omni-directional beacon simultaneously, without causing congestion by their own transmissions. Only one frequency channel is absorbed by the service, and fewer ground staff are required.

There remains, however, the much more difficult problem of finding an alternative to the existing methods of air traffic control. When this is available, in the form of a device for providing warning of collision, the whole civil air transport communication system will be greatly simplified and accelerated. In the meantime, as the author points out, something could be achieved by exercising a greater degree of control before the aircraft leave the ground, rather than by placing exclusive reliance on radio-communication and ground D.F. when the aircraft are already in flight.

No doubt there are objections to the complexity and bulk of the wireless equipment which might have to be carried in the air, but since it is evident that the safety and regularity under all weather conditions, essential to a genuinely commercial transport service, depend principally on various wireless aids, the required sacrifices in space and money ought increasingly to be faced. When economy or other operational conditions involve the employment of small aircraft of limited payload, whose crew consists solely of the pilot, the provision of an efficient safety service devolves almost exclusively on the ground side of the organization and presents an excessively complicated problem.

It is therefore principally in the direction of bettering the aircraft station that an immediate improvement in the general communications organization might be obtained, but this is not solely within the competency of the communications engineer.

Commander F. G. Loring (*communicated*): In connection with the opening sentences of the paper* it may be of interest to record that the Italian delegation to the Radiotelegraph Conference of London in 1912 raised the question of making provision for aeronautical services in the international regulations. The proposal was, however, turned down and postponed until the next conference, which took place in Washington in 1927. At this Conference a small exclusive allocation of 96 kc./s. was made to the aeronautical service and another of 25 kc./s. to the marine service. Both services, however, were free to operate in the general mobile-service allocation if they desired to do so. At the Madrid Conference (1932) the exclusive allocations granted were: aeronautical 70 kc./s., marine 110 kc./s.

At the Cairo Conference of 1938 the principle of allocating exclusive frequencies to individual services was considerably extended. The marine allocation was increased to 885 kc./s. and the aeronautical to 975 kc./s., with an additional allocation of 16 500 kc./s. in the ultra-short-wave band.

I think I am right in saying that the organization of civil aviation radio-communication was not taken very seriously until about 1930, at which date the marine radio organization had been in operation for many years. The Post Office took over the control of the service in 1909.

In 1929 there were 9 400 ships notified to the International Bureau at Berne, and 389 aircraft. In the same year the Post Office stations in Great Britain and Ireland handled over 2½ million paid words of traffic and made over 222 000 separate contacts with ships.

Mr. A. D. Hodgson (*in reply*): I agree with Mr. McPherson that the opening remarks in the paper are perhaps not very precise. Marine radio-communication was, of course, well ahead in the early days of civil aviation, but it was mainly by spark transmission and this was not very applicable to aircraft communication purposes.

A comparison of the number of aircraft radio stations with the number of ship radio stations does not by itself give a clear indication of the number of channels required. The amount of communication required by an aircraft in poor weather is considerably greater than the amount of traffic created by shipping service. Rapidity of service is essential in air transport communication: a ship can drop anchor under the worst conditions, but the aircraft must be brought safely to land on an airport, and, as mentioned in the paper, the difference between the field strength required at the aircraft and that delivered by the aircraft at the ground station results in the ground station having a large interference area. Delays to marine traffic could be tolerated, but there must be no delay to aircraft traffic. Thus as a whole there is the need for a greater frequency-allocation than for marine purposes. The effect of the speed of aircraft is mentioned in the paper.

Recent developments have resulted in an improvement in the performance of the aircraft radio installation, and the replacement of point-to-point radio channels by land-lines has enabled better use to be made of the radio channels. There were in the first place many reasons why a land-line point-to-point service could not be immediately applied, but now (as reference to Fig. 1 will show) the point-to-point channels depend almost entirely on teleprinter working.

With regard to compulsory and voluntary fitting of radio equipment, there are many aircraft outside the compulsory category which carry such equipment, but the factor deciding whether an aircraft will be licensed to carry radio equipment is the purpose for which the aircraft is to be used. Private aircraft used primarily for pleasure purposes cannot at the moment be allowed the indiscriminate use of radio-communication. Perhaps in time to come a service of this nature may be possible as a parallel to the trawler radio-telephone service.

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* Revised for the *Journal*.

Many aircraft which are not compelled to carry radio equipment do carry such items as a receiver for weather-report reception and direction-finding or radio compass receivers.

With regard to public correspondence, there has not so far been any real demand for such a service on short routes, but in August, 1939, a public correspondence service was opened as a trial and arrangements were made for the passage of such telegrams to the Post Office for delivery. On long-distance routes such a service would probably be worth while.

The figures given in Table 3 are intended to apply to a fixed aerial only. The capacitance given may be a little high for some fixed aerials at present in use, but it does not represent a figure which cannot be achieved. The capacitance of the Douglas DC3 aerial is of the order of 170 $\mu\mu$F, and the total circuit resistance, employing the equipment mentioned on page 334, is 8 ohms. On small aircraft the capacitance will, of course, be lower and the resistance higher, but the extreme limit in this direction at present results mainly from the tendency to limit the fixed aerial system to the smallest dimensions possible.

With regard to the figures for attenuation given on page 330, perhaps it should have been indicated that at the shorter distance the height at which this field strength applies is smaller. Mr. McPherson quotes 500 metres, the height at which a landing would commence at a distance of 15 miles; at 2·8 miles the height would not be more than about 50–60 metres. The field strength along the gliding angle of the aircraft increases more rapidly than at a constant altitude, due of course to the vertical directivity employed; hence the need for a high attenuation of false courses.

Vertical polarization has been used hitherto for landing beacons, but, as Mr. McPherson states, horizontal polarization would appear to be desirable and American developments are proceeding on these lines. As Mr. McPherson indicates, considerable interference can be caused on 33 Mc./s. between various beacon installations.

I do not intend to be unfair to British aircraft radio practice, but to show what can be done with care and attention. In the American system shown in Fig. 18 (Plate 2) the transmitters are not tucked away in odd corners, but placed in a very accessible position amidships.

Replying to Mr. Brasher, inter-airport communication by land-line is now superseding radio point-to-point communication, and in fact the position in August, 1939, was such that almost the only radio point-to-point channels were those carrying a service to islands where it was not immediately possible to apply a land-line service.

Mr. Brasher mentions the difficulties experienced in the East due to sabotage of land-lines; failures of this nature are a great weakness of a land-line system. In such circumstances and on difficult land-line routes a radio channel is likely to be much more reliable and less costly. The application of the v.h.f. multi-channel control system is interesting and indicates one of the most useful u.h.f. applications. Mr. Brasher mentions the use of a wavelength of 7 metres: some few years ago I was working on a similar system operating on a wavelength of 1 metre.

I understand that a multi-channel system of this type has been in use in New York Harbour, where an extensive remote-control system, on the step-by-step automatic-telephone principle, applied over a radio circuit, has been used to control the transmitting station from the receiving station. Ultra-high-frequency teletype circuits of this nature are also being used in the U.S.A. and would be advantageous for application in difficult country.

With regard to the question of the positioning of Adcock D.F. systems, remotely situated aerials are in use at various places, including Jersey Airport. It is true that the masts can be placed in the shadow of the airport building and the receiver in the control tower. There is a great deal to be said for arrangements of this nature. The figure of 3 μV/m. for an Adcock system 45 ft. in height, mentioned by Mr. McPherson, should be particularly interesting in this direction. The obstruction requirements applied to airports in this country have, however, resulted in the complete D.F. station being placed some 3–4 miles from the airport.

Concerning the frequencies of 346 and 350 kc./s. and the allocation of frequencies according to the class of aircraft, some steps in this direction have been taken, but if the number of channels required becomes too large considerable difficulties of equipment and staff are likely to occur, and changes of frequency on the route may be necessary, with a resulting increase of communication. In 1939 some relief was obtained by operating all British aircraft on 363 kc./s. between Croydon and the coast, while Continental aircraft made use of 333 kc./s. The outbreak of hostilities of course put an end to the application of the additional frequencies obtained at the Cairo Conference.

With regard to Table 4, it is regretted that owing to present circumstances distances cannot be supplied.

In reply to Group-Captain de Burgh, there is a great deal to be said for separate h.f. and m.f. installations. This has always been felt to be a better proposition than combined equipments, but the demand by operating companies and aircraft manufacturers for a saving in space and weight to the last ounce has been the cause of the introduction of the combined system.

Standardization is most emphatically needed, but attempts in this direction some little while ago were unfortunately not successful.

I am interested to learn that it has been stated in the U.S.A. that there does not appear to be much advantage to be gained by adopting a power-supply voltage above 24 volts. This must be a recent change of front, as the U.S.A. were the first to try a 110-volt supply. A reference to the literature concerned would be appreciated.

With regard to the use of 800-cycle alternating current, I am not aware that any difficulties due to induction have been experienced. The Douglas DC4 machine is understood to have been fitted with an 800-cycle a.c. supply, and it is believed that K.L.M. intended fitting a transmitter employing the unrectified alternating current on the anodes of the output stage and thus giving a 1 600-cycle M.C.W. note. It is not known what results have been obtained.

With regard to static suppression, the trailing-wire scheme is the one referred to. During July and August, 1939, induced static interference and rain static were experienced, particularly by aircraft operating over the East Coast to Denmark and Norway, and it appeared that if the claims made for this device were substantiated it would have been a useful addition.

I am not exactly biased in favour of American practice, but I agree with Group-Captain de Burgh that the Americans are more communication-minded than ourselves. The attitude in England has been to regard the radio equipment as a necessary evil, and as a result American equipment is considerably in advance of our own as regards thought, planning and execution.

In reply to Mr. Spagnoletti, the running costs of land-line circuits are, generally speaking, lower than those of a radio circuit, but there are of course many situations where a wired circuit is not practicable.

The question of crystal-controlled equipment on aircraft installations is quite involved. H.F. equipment is in many cases crystal-controlled, but if all aircraft were crystal-controlled on, for example, 333 kc./s. then little or no latitude of adjustment would be available and jamming would be likely to become worse. Adjustable gaps giving a swing of ± 1–2 kc./s. could of course be used with advantage, and steps are being taken in this direction and also in connection with master-oscillator circuits of very high stability. Such circuits need not, on account of the use of positive- and negative-coefficient ceramic condensers, be particularly heavy. The greatest factor affecting the application of crystal control has no doubt been the changes of frequency which have occurred. Even if warning of an impending change can be given in ample time, there may be aircraft on Empire routes which will be unable to obtain new crystals in time to comply with the change. No doubt when the new frequency band has been applied, the application of crystal control will become general.

The true radio compass certainly has advantages over visual direction-finding or homing and is very much to be advocated, but I believe the equipment has so far proved to be rather heavy. No doubt future developments will produce a true radio compass which will be more useful than the normal rotating-loop direction-finder.

Mr. Rhys-Jones will be interested to learn that routine measurements are made on all equipment, and signal generators are employed for receiver checks.

Mr. Rhys-Jones's remarks on altimeters are interesting. I have heard that some difficulties of this nature have been experienced in experimental work.

Mr. Gill's remarks on the routes in the Eastern Mediterranean are interesting. The application of the new frequencies obtained at the Cairo Conference should go a long way towards the improvement of conditions. It is regretted that it was not possible to deal with the Empire section of the paper in greater detail. There is in the Empire aviation communication service material for a separate paper.

With regard to the issuing of concise instructions, so far as European conditions are concerned the R.S.I.T.A. and Air Ministry Publication 1692, the "Civil Aviation Communication Handbook," give full details of procedure and regulations to be observed, also a list of stations, frequencies, etc. Aircraft operating companies also have handbooks of instructions for their radio officers and pilots. Precise instructions are of course very necessary for the satisfactory operation of the communication system; another essential is close co-operation between ground and air personnel, enhanced by a mutual understanding of the instructions. In this direction the practice adopted by K.L.M. of arranging for operators to have a tour of duty in the air and on the ground has much to recommend it. To enable such a scheme to operate, staff are interchanged with the staff of the Government stations. An understanding by the ground operator of conditions in the air, and by the aircraft operator of conditions on the ground, is most desirable.

The initial training of staff is important, and in this direction I should like to stress the need for a more adequate technical training. Equipment is in general becoming more involved: station installations are more complex, and remote-control and land-line systems call for some knowledge of telegraph and telephone engineering. The acquisition and digestion of this knowledge is, not beyond the capabilities of the average personnel and supervising staff provided they are given an adequate course of instruction by means of lectures, or the circulation of bulletins.

Staff must be enabled to keep abreast of progress in communication systems and in the development and application of new procedure. Again, the use of u.h.f. landing devices necessitates not only a knowledge of the particular equipment itself, but also some appreciation of the behaviour and vagaries of u.h.f. propagation, in order that the performance may be supervised and complaints and reports from pilots understood and dealt with correctly.

My remarks in regard to technical training apply in equal measure to the aircraft radio officer. Clear and concise instructions to radio officers are essential, and the manner in which these instructions are prepared is important.

In reply to Commander Loring, the opening sentences of the paper were intended to convey that in the early days of civil aviation the development of radio-communication in its more modern aspect was just beginning. Communication by means of arc and spark equipment for marine purposes was of course well established, but it was the advent of C.W. telegraphy and of telephony and improvements in the 3-electrode valve which enabled aviation communication to become practicable. In view of Commander Loring's communication I have amended the first paragraph of the paper by substituting the words "radio-communication by continuous-wave telegraphy and telephony" for "radio-communication itself."

INSTITUTION NOTES

ROLL OF HONOUR
(THIRD LIST)[*]

The following members have lost their lives in the service of their country:—

Killed in Action.

Adye, Major A. F. C.	Royal Artillery	Associate Member
Ainley, Lieut. P. E.	Royal Army Ordnance Corps	Associate Member
Brooks, Lieut. H. W.	Royal Naval Volunteer Reserve	Graduate

Killed on Active Service.

Furse, Flying Officer C. W.	Royal Air Force	Graduate

Died on Active Service.

McNeal, Sec. Lieut. G. A.		Graduate

Died of Wounds.

Brigstocke, Lieut. W. G. P.	Royal Naval Volunteer Reserve	Graduate

HONOURS AWARDED TO MEMBERS SERVING WITH H.M. FORCES
(SECOND LIST)[†]

C.B.E.

Sykes, Col. A. C., D.S.O., O.B.E.	Royal Signals	Associate Member

O.B.E.

Leeson, Lieut.-Col. B.H.	Royal Engineers	Member

D.S.O.

Kennedy, Lieut.-Col. J. R.	Royal Engineers	Associate Member

M.C.

Wood, Captain P. T.	Royal Engineers	Associate Member

Mentioned in Despatches.

Mountbatten, Capt. The Rt. Hon. Lord Louis	Royal Navy	Associate Member
Rendle, Sub-Lieut. H. B.	Royal Naval Volunteer Reserve	Associate Member

THE RECEPTION OF MEMBERS' CHILDREN OVERSEAS

Members wishing to take advantage of the generous offer of Canadian engineers to receive into their homes the children of members of the Institutions of Civil, Mechanical, and Electrical Engineers, should communicate with the Secretary irrespective of whether they contemplate their children being evacuated privately or under the Government scheme.

The Institution of Engineers, Australia, is conducting a survey of its members to ascertain to what extent provision could be made for taking care of the children of members of the above three Institutions. This spontaneous action is additional proof of the close bond between engineers throughout the Empire, and of the moral and material support which is being received from the Dominions during the present war. Members interested should apply to the Secretary for details to be sent to them when available.

MEMBERS FROM OVERSEAS

The Secretary would be glad if members coming home from overseas would inform him whenever possible in advance of their visit, stating their address in this country even if they do not wish a change of address recorded in the Institution Register.

The object of this request is to enable him to advise members visiting this country of the various meetings and functions of The Institution and its Local Centres and, when occasion arises, to put them into touch with other members.

The Secretary would also be pleased to receive visits from overseas members and to assist them in any way possible during their stay in the United Kingdom.

OVERSEAS ACTIVITIES

Argentina

On the 19th May, 1939, the Chairman of the Local Centre, Mr. W. E. Tremain, Member, delivered his Inaugural Address, the subject being " Television " (see vol. 86, p. 460).

At a meeting held on the 16th June, 1939, Mr. R. J. Musto, Associate Member, read a paper entitled " Some Technical Aspects of Electric Arc Welding."

On the 21st July, 1939, a paper on " Problems arising from Change of Frequency of Railway Bulk Electric Supply " was read by Mr. R. Wright, Member.

At a meeting held on the 18th August, 1939, Mr. C. T. T. Comber, Associate, read a paper entitled " Notes on Telephone and Telegraph Insulators."

At a meeting held on the 16th September, 1939, a paper on " Electromagnetic Theory of Light and Optical Surfaces " was read by Mr. E. Berry, Associate Member.

On the 17th May, 1940, the new Chairman, Mr. M. F. Ryan, C.B.E., Member, delivered his Inaugural Address, the subject being " Job Analysis."

Australia

Queensland.

At a meeting held on the 20th June, 1939, at which 30 members and visitors were present, a paper by Mr. W. H. Flanigan entitled " Electricity Supply from the Contractor's Point of View " was read.

On the 28th July, 1939, Mr. L. G. Pardoe, Associate

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[*] See *Journal I.E.E.* **86**, p. 510, and **87**, p. 110.
[†] See *Journal I.E.E.*, **86**, p. 510.

Member, read a paper entitled "Some Notes on Supervisory Control." Forty members and visitors were present.

A Joint Meeting of local members of the I.E.E. and members of the Brisbane Division of The Institution of Engineers, Australia, was held on the 10th August, 1939. The subject discussed was "The Engineer's Part in National Defence," and was introduced by Col. A. P. Pyne, Member, and Major D. J. Garland, B.E., of the Australian Institution. The attendance numbered 23.

At a meeting held on the 31st August, 1939, which was attended by 50 members and visitors, Mr. A. E. Sharman read a paper entitled "Voltage Regulation of Transmission and Distribution Systems."

The annual social gathering of the local I.E.E. members was held on the 28th September, 1939, at the Belle Vue Hotel, Brisbane. The Chairman, Mr. J. S. Just, welcomed the guests, among whom were representatives of the local scientific Institutions.

Western Australia.

At a meeting held on the 28th August, 1939, Mr. W. H. Taylor, Associate Member, read a paper entitled "Electricity Supply in Western Australia."

The annual dinner was held on the 14th September, 1939, at the Savoy Hotel, Perth. The Lieut.-Governor was among those present.

Ceylon

The 5th Annual General Meeting of the Local Committee was held on the 25th February, 1939, at Fort Colombo under the chairmanship of Major C. H. Brazel, M.C., and was attended by 12 members. The meeting was followed by a dinner.

China

At a Joint Meeting, held on the 16th October, 1939, of the China Centre of the I.E.E., The Engineering Society of China, The Institution of Civil Engineers (Shanghai Association), and The Institution of Mechanical Engineers (China Branch), a paper by Mr. S. Flemons, Member, entitled "Administrative Management in Engineering and other Organizations" was read and discussed.

A further Joint Meeting was held, under the auspices of the Engineering Society of China, on the 30th October, 1939, when a paper by Mr. C. J. Merritt entitled "The Warming of Buildings by Electrical Thermal Storage" was read.

A further Joint Meeting, attended by 48 members and visitors, was held on the 4th December, 1939, when Mr. A. B. Wilkinson, Associate, read a paper on "Telephone Traffic Engineering."

On the 8th January, 1940, a Joint Meeting was held under the auspices of the I.E.E. China Centre. A paper by Mr. W. A. Ankerson, B.Sc.(Eng.), Associate Member, entitled "The Electric Motor: its Development and Some Factors governing the Selection of Machines," was read and discussed.

A further Joint Meeting, in which 37 members and visitors took part, was held on the 5th February, 1940, when a paper entitled "Notes on Cost Allocation for Rate Construction in the Electric Supply Industry" was read by Mr. R. L. Evans, Associate Member.

On the 18th March, 1940, a further Joint Meeting was held at which Mr. J. T. Rogers, Associate Member, read a paper on "Transmission over Coaxial Cables." Forty-eight members and visitors attended the meeting.

A further Joint Meeting was held on the 4th March, 1940, when a paper entitled "Street Traffic Control Signals, with particular reference to Vehicle Actuation" was read by Mr. W. Miles, Associate Member, on behalf of the author, Mr. F. G. Welch.

The Annual Dinner of the I.E.E. China Centre was held jointly with the local representatives of the Institutions of Civil and Mechanical Engineers on the 5th April, 1940, 112 members and guests being present. The latter included Mr. A. H. George, C.M.G. (H.B.M. Consul-General), Sir Robert Calder-Marshall, K.B.E. (Chairman of the British Chamber of Commerce), Mr. J. C. Hutchison, O.B.E. (H.B.M. Commercial Counsellor), and Mr. C. S. Franklin (Chairman of the Shanghai Municipal Council). Mr. J. Haynes Wilson, Chairman of the Centre, in proposing the toast of "The Guests," reviewed the "History of The Institution," a copy of which had just come into his possession.

India

Bombay.

On the 12th August, 1939, a visit was paid to the transmitting station of All-India Radio at Worli.

The annual social gathering of local members and their guests, who on this occasion numbered 95, was held on the 20th November, 1939, at the Taj Mahal Hotel. Several short engineering films were shown.

On the 9th December, 1939, a party of 40 members inspected the track-recording car of the G.I.P. Railway, an account of which had previously been given by Mr. H. J. Mulleneux at the meeting held on the 18th April, 1939.

On the 22nd February, 1940, Mr. W. Price, Associate Member, gave a short talk on "Meters and Meter Testing" to a gathering of 89 members and guests, who were later conducted round the Meter Testing Department of the Bombay Electric Supply and Tramways Co., Ltd.

At a meeting held on the 28th March, 1940, attended by 70 local members and guests, Mr. G. Fowler, Associate Member, read a paper entitled "The British Grid River-Thames Crossing at Dagenham." The paper was followed by a cinematograph film.

Calcutta.

On the 18th January, 1940, Mr. S. W. Redclift, Member, read a paper on "Suggestions for the Development of Electric Power in Bengal" before an audience of 55 members and their guests. A discussion followed which was continued at a further meeting held on the 15th February, at which 35 members and guests were present.

On the 14th March, 1940, Mr. W. G. Cross, Associate, read on behalf of the author (Mr. G. F. Sinclair) the paper on "The Trolleybus" (see vol. 86, p. 225).

At a meeting held on the 30th May, 1940, Mr. C. P. Storr, B.A., Associate Member, read a paper entitled "Some Notes on the Installation and Maintenance of Automatic Protective Equipment."

Madras.

On the 10th May, 1939, Mr. G. Yoganandam, Associate Member, read a paper on "The Development of Hydro-Electric Power in Southern India" before an audience of 33.

At a meeting held on the 12th July, 1939, which was attended by 32 members, Mr. P. Govindakrishnayya, Graduate, read a paper entitled "The Diesel Engine as a Power Unit for Generating Electrical Energy."

BRITISH STANDARDS

The Secretary has been asked by the British Standards Institution to draw attention to the following new and revised specifications, copies of which can be obtained from the British Standards Institution, Publications Department, 28, Victoria Street, London, S.W.1, price 2s. 3d. each post free.

Dimensions of Instrument Jewels (B.S. 904).

In response to a request received from the Air Ministry, a British Standard Specification has been prepared for the dimensions of instrument jewels. The Specification applies to compass jewels and to "V" jewels and ring and end stones for instruments other than watches and clocks and integrating meters.

The principal object of this standardization has been the simplification of a wide diversity of sizes and types of instrument jewels. The overall dimensions and tolerances are given for a limited number of sizes of jewels of each type, together with particulars of the form of the hole or recess. The concentration of manufacture and demand on these limited types and sizes will, it is confidently anticipated, considerably expedite jewel production in this country.

The Appendix to the Specification gives notes on alternative methods of inspecting jewels, with particular reference to the general form and angle of the recess.

Radio-Interference Suppression (B.S. 905 and B.S. 613).

The recent issue of one new and one revised B.S. Specification dealing with the suppression of radio interference brings the total number of Specifications on this subject up to six—providing probably the most comprehensive series of standards issued by any country.

The new Specification just published is B.S. 905, Anti-interference Characteristics and Performance of Radio Receiving Equipment. It prescribes the general conditions to be complied with in the design of radio receiving equipment, and gives guidance on the method of installing such equipment and interference suppression devices with the object of minimizing the effects of radio interference. In addition to being of importance to the makers of radio receivers, the Specification is also of particular interest to the users of receivers, as it helps them to eliminate interference emanating from sources beyond their control. Some pertinent remarks are made about inefficient aerials, and a section is devoted to the characteristics and performance of "anti-interference" aerial systems. Another section deals with community aerials specially designed to permit the simultaneous operation of two or more receivers from the same aerial. The methods of eliminating radio interference from the electric supply mains and means of protection against atmospheric electricity are described.

The revised Specification mentioned above is B.S. 613, Components for Radio-interference Suppression Devices (excluding devices for traction, marine and other special equipment). The reference to marine equipment as one of the items excluded from the scope of the Specification is significant. A separate Specification dealing with the suppression of radio interference on board ship has been drafted, and copies of the proof are available to those interested. As far as the Specification proper is concerned, the new edition of B.S. 613 differs somewhat as regards details, particularly in the section relating to capacitors. Two entirely new Appendices have been added, dealing respectively with shock and earth-leakage considerations and with wiring and maintenance. The Appendix giving suggested values of components for various types of suppressors has been extended and revised in the light of the experience gained since the first edition of the Specification was published.

Steel Conduits and Fittings (B.S. 31).

B.S. 31—1933 for Steel Conduits and Fittings for Electrical Wiring has just been revised. The revision was undertaken principally with the view to clarifying the position of the lugs relative to the spout outlets in small circular boxes, and the Table giving the dimensions of the entry bushes has also been slightly amended.

Tungsten Filament General Service Electric Lamps (B.S. 161).

A new edition of this Specification has just been published. The actual modification is only a small one, viz. the raising of the efficiency of the 150-watt lamp and the change of the cap of the 200-watt lamp. It was felt that a new edition should be issued, however, as there had been an addendum slip to the 1937 edition which added a schedule for low-voltage coiled-coil filament lamps. There were also one or two printing errors in that edition which have been corrected in the new issue.

MEMBERS ON SERVICE WITH H.M. FORCES (SIXTH LIST)*

(Note.—The Secretary will be glad to receive, for publication in subsequent lists, the names of other members of The Institution who are serving with His Majesty's Forces, together with particulars of their rank and the unit in which they are serving. A Roll of Honour, and lists of honours awarded, promotions, transfers, etc., are also being published from time to time.)

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* See *Journal I.E.E.*, **85**, p. 653; **86**, pp. 99, 308 and 511; and **87**, p. 110.

Members

Name	*Corps, etc.*	*Rank*
Baker, J. H.	Royal Signals	Captain
Calverley, J. E.	Royal Engineers	Sec. Lieut.
Kidd, W.	Royal Air Force (V.R.)	Squadron Leader
Lawrie, T.	Royal Naval Volunteer Reserve	Sub-Lieut.
North, B.	Royal Engineers	Lieutenant
St. John, E. C.	Royal Engineers	Major
Sharp, G. D.	Royal Navy	Commander

Associate Members

Name	*Corps, etc.*	*Rank*
Allen, M.	Royal Engineers	Sapper
Atkins, A. H.	Royal Artillery	Major
Bartlett, H. V.	Royal Navy	Lieut.-Comdr.
Calveley, C. E.	Royal Signals	Sec. Lieut.
Carey, F. T.	Royal Army Ordnance Corps	Lieutenant
Carr, A. S.	Royal Air Force (V.R.)	Pilot Officer
Clothier, G. D.	Royal Engineers	Major
Craven, A.	Royal Air Force (V.R.)	Squadron Leader
de Nordwall, C. H.	Officer Cadet Training Unit	Cadet
Dixon, A.	Royal Engineers	Sec. Lieut.
Fox, P. S.	Royal Naval Volunteer Reserve	Lieutenant
Frost, A. H.	Royal Engineers	Captain
Garratt, G. R. M.	Royal Air Force	Flt.-Lieut.
Gill, W. E.	Royal Signals	Captain
Girdlestone, R. O.	Royal Army Ordnance Corps	Lieutenant
Hobson, R. J.	Royal Engineers	Sec. Lieut.
Hunter, F. G.	Royal Navy	Captain
Irwin, C. K.	Royal Army Service Corps	Sec. Lieut.
Land, J. E.	Royal Artillery	Captain
Lewis, G. B.	Royal Naval Volunteer Reserve	Lieutenant
Long, R. F.	Royal Army Service Corps	Captain
Lord, C. G.	Royal Artillery	Sec. Lieut.
Murrell, A. P. C.	Royal Naval Volunteer Reserve	Lieutenant
Pearce, K. M.	Royal Army Ordnance Corps	Lieutenant
Randle, G. H.	Royal Air Force	Wing-Comdr.
Renton, R. N.	Royal Signals	Lieutenant
Robinson, A.	Royal Naval Volunteer Reserve	Sub-Lieut.
Samuelson, H. M.	Royal Air Force	Flt.-Lieut.
Sims, K. E.	Royal Naval Volunteer Reserve	Sub-Lieut.
Smith, M. J.	Royal Air Force	Sergt.-Pilot
Solomon, T. H.	Royal Engineers	Major
Southgate, A.	Royal Air Force	Flt.-Lieut.
Speedy, G. M. E.	Royal Naval Volunteer Reserve	Lieutenant
Stonebanks, A. M.	Royal Signals	Lieutenant
Teather, R. H.	Royal Signals	Sec. Lieut.
Thompson, F. S.	War Office	Major
Toogood, H. de C.	War Office	Major
Warhurst, F.	Royal Signals	Sec. Lieut.
Wells, W. H.	Royal Engineers	Sec. Lieut.
Whitney, J. S.	Royal Engineers	Captain
Youatt, B. D.	Royal Navy	Lieut.-Comdr.

Associates

Name	*Corps, etc.*	*Rank*
Butcher, H.	Royal Engineers	Sec. Lieut.
Carr, C. B.	War Office	Captain
Dickinson, R. H.	Royal Army Service Corps	Captain
Murray-Alston, B. E.	Royal Artillery	Sec. Lieut.
Ross, J. H.	Royal Army Ordnance Corps	Captain
Thornton, T. J. E.	Royal Air Force	Wing-Comdr.
Walmsley, T.	Royal Signals	Major
Worby, A. E.	Fleet Air Arm (R.N.V.R.)	Lieutenant

Graduates

Name	*Corps, etc.*	*Rank*
Adams, E. F.	Royal Engineers	Sec. Lieut.
Allison, S. S. H.	Royal Signals	Signalman
Babb, A. H.	Royal Engineers	Sec. Lieut.
Bateson, A.	Royal Signals	Lance-Corporal
Beattie, M. H.	Royal Signals	Sec. Lieut.
Bennett, W. G.	Royal Engineers	Sec. Lieut.
Bentley, D. V. C.	Royal Army Ordnance Corps	Lieutenant
Bird, J. F.	Royal Artillery	Captain
Bishop, D. O.	Royal Air Force (V.R.)	Flying Officer
Campbell, A. H.	Royal Signals	Captain
Cochrane, T. R. H.	Royal Naval Volunteer Reserve	Sub-Lieut.
Collop, A. D.	Royal Naval Volunteer Reserve	Sub-Lieut.
Cooper, D. G.	Royal Air Force (V.R.)	Pilot Officer
Des Brisay, A. W. Y.	Royal Signals	Major
Drayton, C. R.	Royal Engineers	Sapper
Edmonds-Brown, H. E.	Royal Signals	Sec. Lieut.
Epstein, E. N.	Royal Signals	Corporal
Frazer, T. A.	Royal Naval Volunteer Reserve	Lieutenant
Garrity, H. A.	Royal Air Force (V.R.)	Pilot Officer
Gordon, E. R.	Royal Engineers	Sapper
Gozzard, J.	Royal Naval Volunteer Reserve	Sub-Lieut. (E)
Griffiths, W. F.	Royal Signals	Sec. Lieut.
Harris, D. J.	Royal Signals	Sec. Lieut.
Hart, A. R.	Royal Air Force (V.R.)	Pilot Officer
Hatfield, S. A.	Royal Air Force	Pilot Officer
Hawkins, W. G.	Royal Army Service Corps	Private
Henn-Collins, C. A.	Royal Signals	Captain
Hensler, E.	Royal Army Ordnance Corps	Lieutenant
Hewett, M. H.	Royal Army Ordnance Corps	Lieutenant
Hounsom, G. R.	Royal Naval Volunteer Reserve	Sub-Lieut.
Innes-Crump, J. E.	Royal Air Force	Squadron Leader
Jones, D. G.	Royal Signals	Cadet
Knight, A. D.	Royal Air Force	Pilot Officer
Lambert, A. P.	Royal Naval Volunteer Reserve	Sub-Lieut.
Longman, D. M.	Royal Engineers	Sec. Lieut.
Marriott, T. W.	Auxiliary Military Pioneer Corps	Private
Martin, N. T.	Royal Engineers	Sapper
Mears, R. J.	Royal Army Ordnance Corps	Lieutenant
Monteath, G. D.	Royal Air Force (V.R.)	Pilot Officer
Morton, J. R.	Royal Army Ordnance Corps	Lieutenant
Neal, H.	Royal Army Ordnance Corps	Lieutenant
Newman, H. D.	Royal Air Force	Flt.-Lieut.
Newton, H. O.	Royal Air Force	Pilot Officer
Nicholson, E.	Royal Signals	Sec. Lieut.
Orr-Ewing, C. I.	Royal Air Force (V.R.)	Squadron Leader
Osborn, P. D.	Royal Engineers	Staff Sergt.

Name	*Corps, etc.*	*Rank*
Packer, J. L.	Royal Signals	Sec. Lieut.
Phethean, J. F.	Royal Engineers	Sapper
Phillips, P. C.	Royal Army Ordnance Corps	Lieutenant
Porter, J. H.	Royal Naval Volunteer Reserve	Sub-Lieut.
Pratt, T.	Royal Air Force (Special Duties Branch)	
Probert, G. O.	Royal Signals	Sec. Lieut.
Rankin, C. A.	Royal Naval Volunteer Reserve	Sub-Lieut.
Rawnsley, C. F.	Royal Air Force	Sergeant
Roberts, D. N.	Royal Engineers	Sapper
Ryan, H. N.	Royal Army Service Corps	Sec. Lieut.
Salt, T. C. F.	Royal Army Ordnance Corps	Lieutenant
Scott-Maxwell, I. S.	Royal Artillery	Sec. Lieut.
Smith, E.	Royal Naval Volunteer Reserve	Sub-Lieut.
Smith, W. E.	Royal Naval Volunteer Reserve	Sub-Lieut.
Speakman, R. H.	Royal Artillery	Sec. Lieut.
Thomas, J. C.	Royal Army Service Corps	Corporal
Thomson, A. S.	Royal Signals	Signalman
Truter, A. M.	Royal Engineers	Sec. Lieut.
Walters, H. R.	Royal Artillery	Sec. Lieut.
Ward, I. M. L.	Royal Engineers	Sec. Lieut.
Watters, W. M. S.	Royal Air Force (V.R.)	Pilot Officer
Wilcox, L. E.	Royal Air Force (V.R.)	Pilot Officer
Wilson, N. J.	Royal Naval Volunteer Reserve	Sub-Lieut.
Yeates, G. A.	Royal Engineers	Cadet
Yorke, R.	Royal Army Service Corps	Private
Youatt, D.	Royal Naval Volunteer Reserve	Lieutenant

Students

Name	*Corps, etc.*	*Rank*
Abraham, N. A.	Royal Naval Volunteer Reserve	Sub-Lieut.
Atkinson, B. W.	Royal Artillery	Gunner
Barnett, A. E. E.	Royal Naval Volunteer Reserve	Sub-Lieut.
Barton, B.	Royal Army Service Corps	Driver
Bowler, J. E.	Royal Army Ordnance Corps	Staff Sergt.
Carpenter, V. S.	Royal Engineers	Sapper
Coggins, W. A.	Royal Army Ordnance Corps	Private
Coventry, J. H.	Royal Engineers	Sapper
Cranham, S. G.	Royal Army Ordnance Corps	Private
Davies, P.	Royal Air Force	A.C.2
Davy, A. G. J.	301st Infantry Training Corps	Lance-Corporal
Deacon, L. W. R.	Royal Army Service Corps	Captain
Dickinson, S.	Royal Naval Volunteer Reserve	Sub-Lieut.
Donelly, H. E. A.	Officer Cadet Training Unit	Cadet
Duckett, G. C.	Royal Naval Volunteer Reserve	Sub-Lieut.
Goss, V. G. S.	Royal Naval Volunteer Reserve	Sub-Lieut.
Griffin, J. G.	Officer Cadet Training Unit	Cadet
Hargreaves, H. R.	Royal Naval Volunteer Reserve	Sub-Lieut.
Henley, W. R.	Royal Signals	Signalman
Hirst, G. T.	Royal Signals	Cadet
Holberton, A. J.	Royal Army Service Corps	Sec. Lieut.
Huey, E. B.	Royal Naval Volunteer Reserve	Sub-Lieut.
Hunt, P.	Middlesex Regiment	Lance-Corporal
Hutchings, C. G.	Royal Air Force	Aircraftman
Jones, C. F.	Ox. and Bucks Light Infantry	Private
Knights, H. R.	Royal Naval Volunteer Reserve	Sub-Lieut.
Leach, A. A. J.	Royal Naval Volunteer Reserve	Sub-Lieut.
Leaning, A. T.	Royal Air Force	A.C.2
Lilburn, A. J.	Royal Naval Volunteer Reserve	Sub-Lieut.
Linay, A. S.	Royal Air Force (V.R.)	Leading Aircraftman
Love, W.	Royal Army Service Corps	Lance-Corporal
McDonald, N. A.	Royal Naval Volunteer Reserve	Sub-Lieut.
McLeod, D.	Royal Air Force (V.R.)	Pilot Officer
Maguire, O. G.	Royal Navy	Electrical Artificer
Mansfield, I. H.	Royal Signals	Signalman
Messenger, H.	Royal Engineers	Sapper
Mills, A. G.	Royal Engineers	Sapper
Moore, R. V.	Royal Navy	Sub-Lieut.
Newsome, W. A.	Royal Engineers	Cadet
Ord, J. A.	Royal Signals	Cadet
Outhwaite, R.	Royal Artillery	Bombardier
Page, H. R.	Royal Artillery	Gunner
Page, S.	Royal Engineers	Sapper
Pearce, A. P.	Royal Air Force (V.R.)	Pilot Officer
Phillips, W.	S.A. Engineers Corps	Lance-Corporal
Pitman, D. T.	Royal Navy	Sub-Lieut.
Poyser, R. W. R.	Royal Engineers	Sapper
Purvis, W. J.	Royal Naval Volunteer Reserve	Lieutenant
Raistrick, R. H.	Royal Army Ordnance Corps	Lieutenant
Richmond, J. R. W.	Royal Naval Volunteer Reserve	Sub-Lieut.
Roberts, J. A.	Officer Cadet Training Unit	Cadet
Robinson, D. W.	Royal Air Force (V.R.)	Pilot Officer
Rogers, M. Y.	Royal Signals	Signalman
Romans, G. O.	East Yorks Regiment	Private
Sanders, J. N.	Royal Air Force (V.R.)	A.C.2
Scott, W. H.	Royal Artillery	Gunner
Seymour, J.	Royal Army Service Corps	Captain
Slyfield, D. W.	Royal Signals	Signalman
Smellie, G. H.	Royal Navy	Wireman
Smith, J.	Royal Army Ordnance Corps	Private
Solomon, T. M.	School of Anti-Aircraft Defence (Wireless Wing)	Acting Sergeant
Somerford, H. W.	Royal Army Ordnance Corps	Lieutenant
Spencer, E. J. C.	Royal Signals	Sec. Lieut.
Sykes, W. H.	Royal Air Force	A.C.2
Taylor, W. G.	Royal Naval Volunteer Reserve	Sub-Lieut. (E)
Turner, G. F.	Royal Air Force (V.R.)	Pilot Officer
Walker, G. R.	Royal Signals	Signalman
Watson, P. A.	Royal Naval Volunteer Reserve	Sub-Lieut.
Westgate, R. G.	Royal Naval Volunteer Reserve	Sub-Lieut.
Whitelegg, J. W.	Royal Air Force	Corporal
Windows, C. E.	Royal Artillery	Sergeant Instructor
Wodehouse, P. A.	Royal Air Force	Leading Aircraftman

PROMOTIONS AND TRANSFERS OF MEMBERS ON SERVICE WITH H.M. FORCES (FOURTH LIST)*

Members

Name	*Corps, etc.*	*Rank*
Leeson, B. H.	Royal Engineers	Colonel
Sparks, A. C.	Royal Engineers	Major

Associate Members

Name	*Corps, etc.*	*Rank*
Barnett, H. E.	Royal Army Ordnance Corps	Captain
Blair, D. C.	Royal Signals	Captain
Bullard, C.	Royal Army Ordnance Corps	Lieut.-Col.
Dunford, A.	Royal Marines	Captain
Edes, N. H.	Royal Signals	Lieut.-Col.
Fuller, A. C.	Royal Signals	Major-General
Harding, R. J.	Royal Army Ordnance Corps	Captain
Johnstone-Hall, F. C.	Royal Army Ordnance Corps	Lieut.-Col.
Lendrum, H. L.	Royal Engineers	Major
McDonald, A.	Royal Signals	Major
McNaughton, A. G. L.	1st Canadian Division	Lieut.-General
Martin, T. G.	Royal Engineers	Captain
Pass, C. W.	Royal Army Ordnance Corps	Captain
Paterson, D. R.	Royal Signals	Major
Perowne, L. E. C. M.	Royal Engineers	Major
Gardner, A. J.	Royal Naval Volunteer Reserve	Lieutenant
Grout, E. J.	Royal Army Ordnance Corps	Captain
Hopkinson, A. F.	Royal Army Ordnance Corps	Major
Hopkinson, C. F.	Royal Army Ordnance Corps	Captain
Ingham, L.	Royal Naval Volunteer Reserve	Lieutenant
Kennedy, J. D.	Royal Army Ordnance Corps	Captain
Marshall, D.	Royal Engineers	Sec. Lieut.
Mason, T. F. V.	Royal Army Ordnance Corps	Captain
Morgan, J. T.	Officer Cadet Training Unit	Cadet
Munton, R. D.	Royal Army Ordnance Corps	Lieutenant
Newman, D. F. W.	Royal Engineers	Sec. Lieut.
Preston, G. N.	Royal Army Ordnance Corps	Major
Saunders, J. M.	Royal Army Ordnance Corps	Captain
Small, W. H.	Royal Artillery	Bombardier
Swinney, E.	Royal Air Force	Flying Officer
Tatham, F. E.	Royal Army Ordnance Corps	Major
Volum, W. G.	Royal Army Ordnance Corps	Lieutenant
Webb, E. T. A.	Royal Naval Volunteer Reserve	Lieutenant

Associate

Name	*Corps, etc.*	*Rank*
Maddocks, W. A.	Royal Artillery	Major

Graduates

Name	*Corps, etc.*	*Rank*
Bird, W. A.	Royal Engineers	Lance-Sergeant
Brodrick, A. G.	Officer Cadet Training Unit	Cadet
Cramb, A. L.	Royal Naval Volunteer Reserve	Lieutenant
Crawshaw, G.	Royal Signals	Lance-Corporal

Students

Name	*Corps, etc.*	*Rank*
Chalmers, G. R.	Royal Engineers	Lance-Corporal
Choppen, D. A. E.	Royal Artillery	Gunner
Davies, E. J. L.	Royal Air Force	Leading Aircraftman
Edelsten, W. K.	Royal Air Force	Corporal
Edwards, E. T. A.	Royal Engineers	Lance-Corporal
Sampson, D. P.	Officer Cadet Training Unit	Officer Cadet
Simpson, K. G.	Royal Army Ordnance Corps	Corporal
Stewart, A. C.	Royal Naval Volunteer Reserve	Lieutenant
Turner, J. C. S.	Royal Air Force (V.R.)	Pilot Officer

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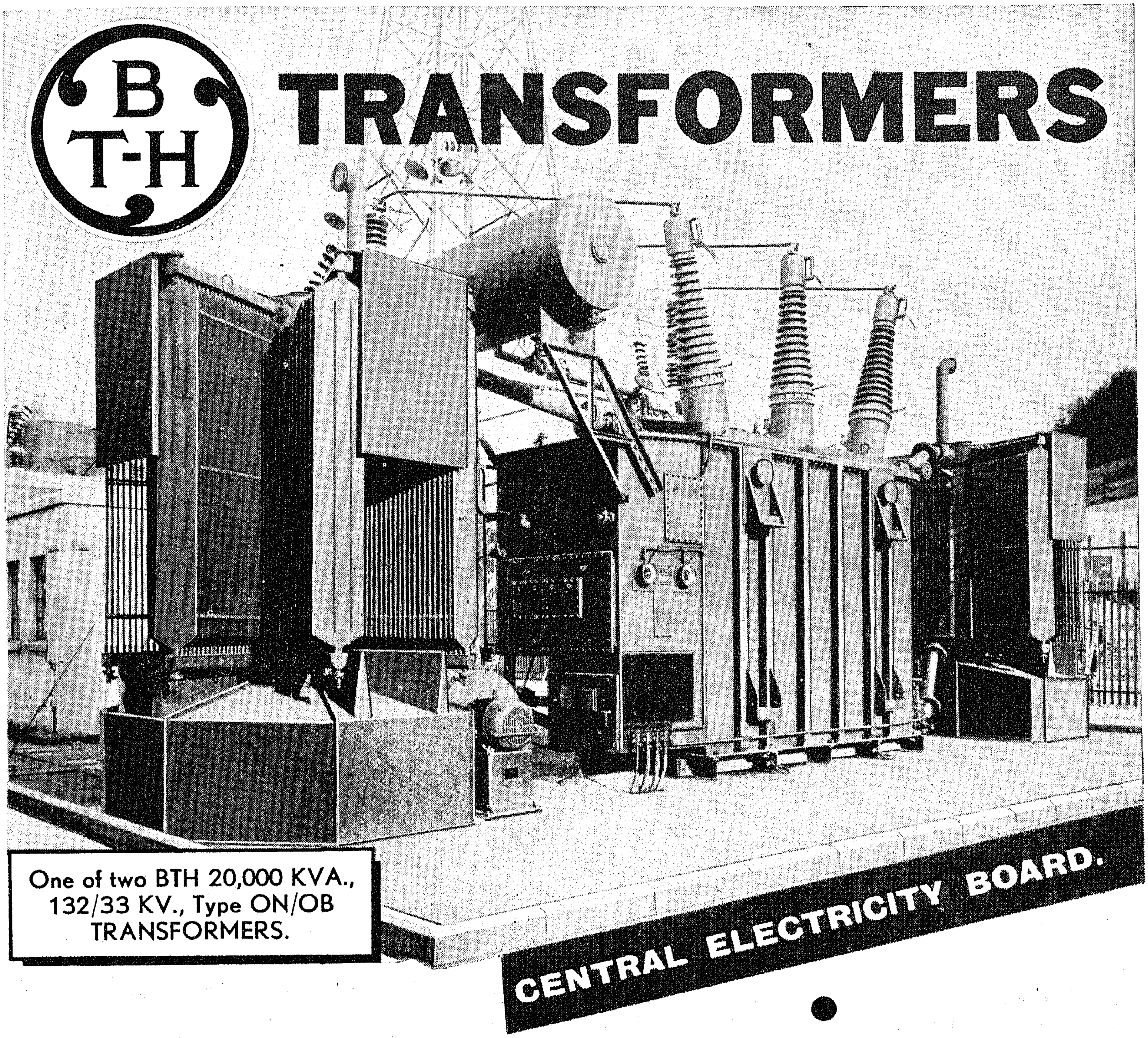
* See *Journal I.E.E.*, **86**, p. 510, and **87**, p. 110.

TRANSFORMERS



One of two BTH 20,000 KVA., 132/33 KV., Type ON/OB TRANSFORMERS.

CENTRAL ELECTRICITY BOARD.

Shielded, 132 KV. windings.
Built-in, on-load tap changing equipment.
Pillar type coolers.
Low pressure air blast cooling.

We make all types of TRANSFORMERS.

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THE BRITISH THOMSON-HOUSTON COMPANY LIMITED, RUGBY, ENGLAND.

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HAVE you considered the use of Condenser Cones for the electrical reinforcement of cable ends in service and for factory testing? There is a complete range of sizes from 8½ inches to 50 inches. The 50 inch Cone shown in the illustration is intended for short time voltage breakdown tests up to 280 kV on Super Tension Cables.

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Standard Telephones and Cables Limited

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Telephone: Albert Dock 1401

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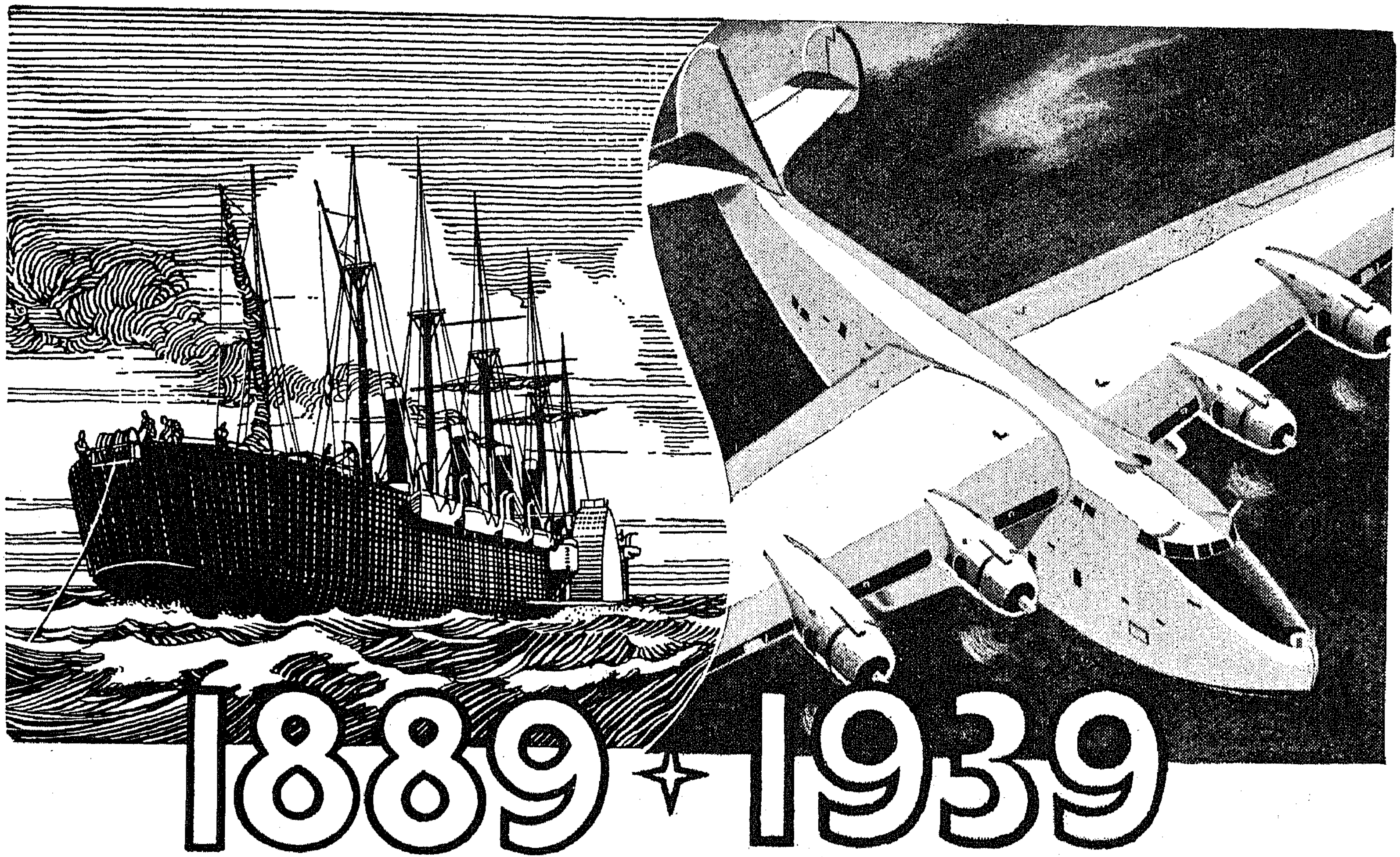

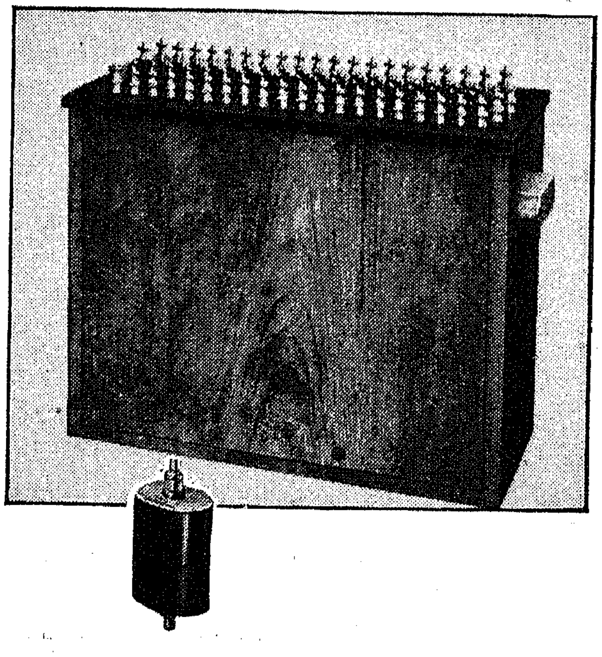

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THESE TWO MUIRHEAD CONDENSERS MAKE history. The one above is retiring after 50 years' faithful service in a circuit where high insulation is essential. It is being pensioned off because 2 of its 40 sections are now below standard, though the remainder still have an insulation resistance of 17,000 megohms per micro-farad at 20° C. ! The lower condenser, specially designed for use in aircraft flying alternately in arctic and tropical conditions, has a different form but the same character. It is just starting on its career, and we have no fear of the story which will be written about *this* condenser 50 years from now.

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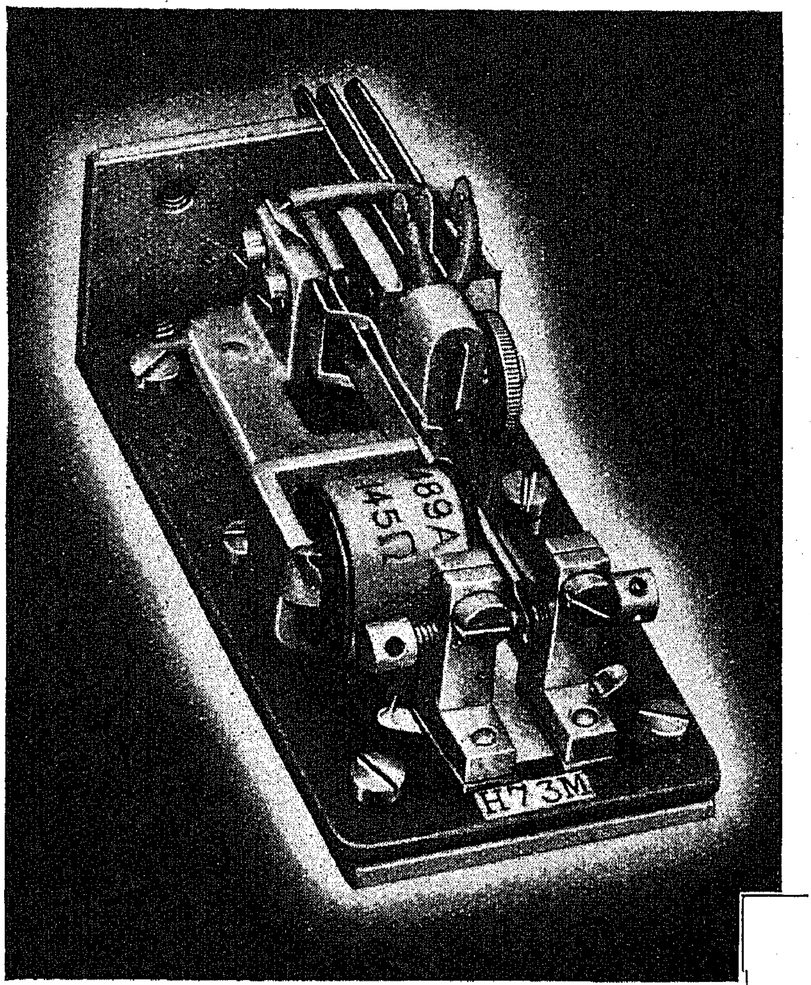
FOR OVER 60 YEARS DESIGNERS & MAKERS OF PRECISION INSTRUMENTS

C. R. Casson 22

SIEMENS

HIGH-SPEED RELAY

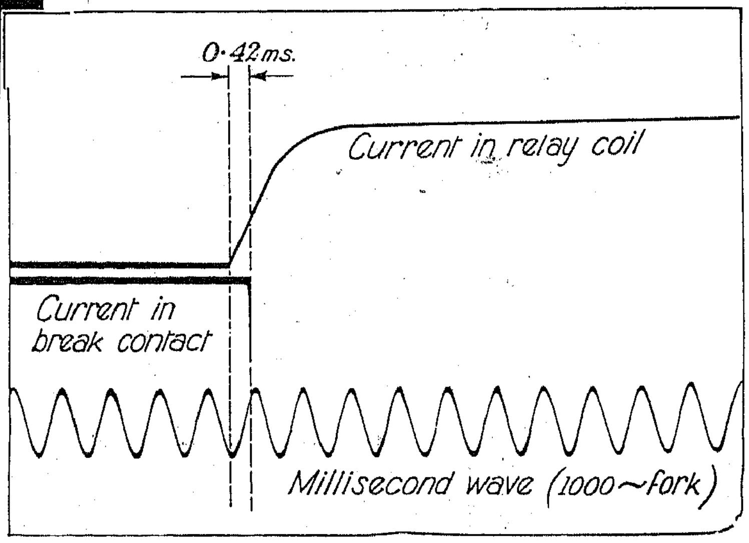


This relay was originally designed to arrest the drive of our Motor Uniselector. The time available for the testing operation with this switch is of the order of ·0005 second.

The relay with its features of:—

Robust construction—Small size and weight—Simple and easy adjustment—Extremely rapid operation and release—and Insensitivity to external mechanical and Electrical disturbances, has provided a solution to many other problems, not only in the telephone art but also in other fields of communication and general signalling.

Examples of some of its applications are detailed below.



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IT HAS—

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—AND IT MAY SOLVE YOUR PROBLEM—

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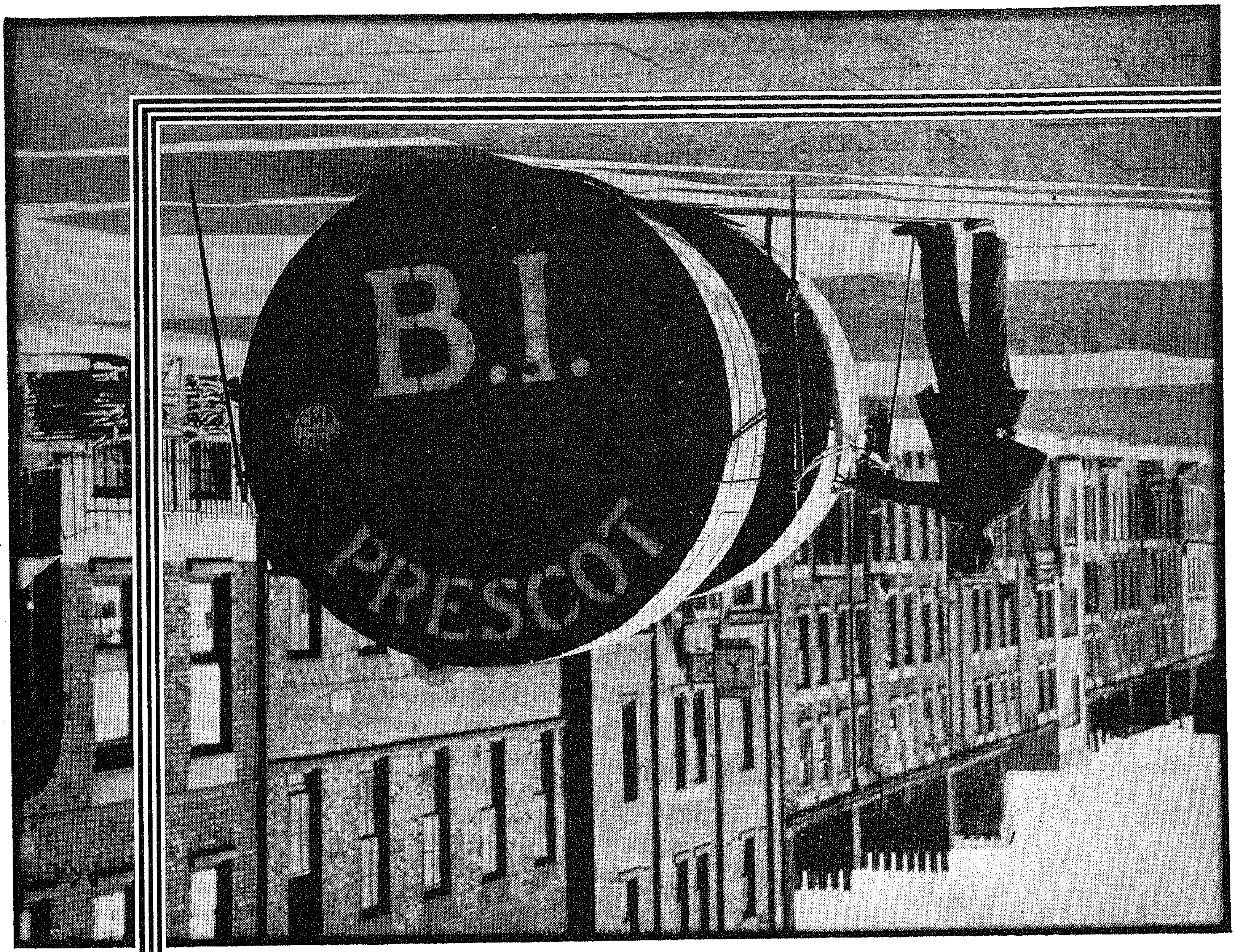

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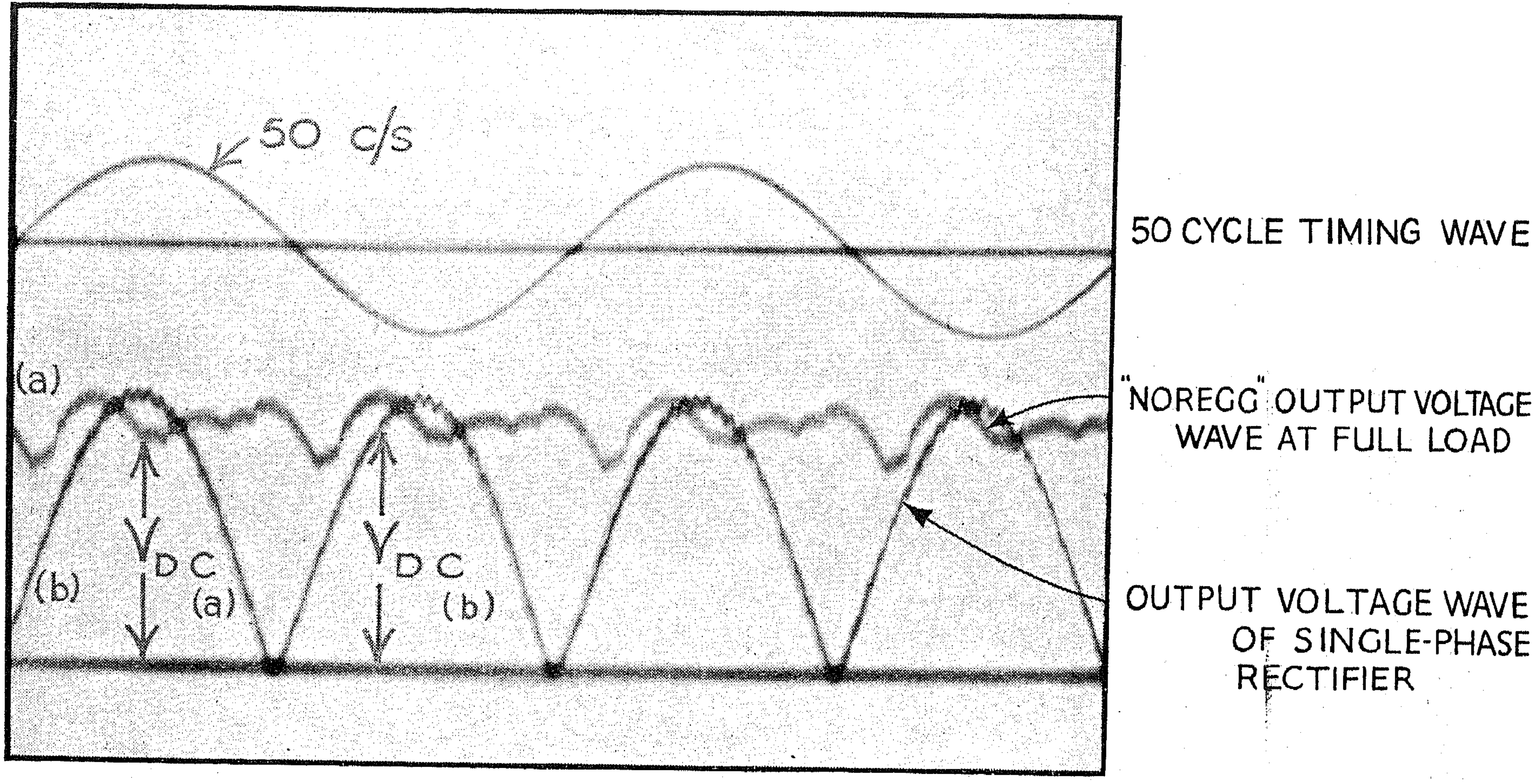

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OF THE MEAN D.C. VOLTAGE AS COMPARED WITH 50% FOR A NORMAL SINGLE-PHASE RECTIFIER

An important feature of the new Westinghouse "NOREGG" constant potential system, for use without batteries, is its ease of smoothing. The circuit is so arranged that, at full load, the secondaries of the mains transformer provide a 3-phase system. The output at full load is of the same order and frequency, therefore, as a normal 3-phase rectifier (about 10 % at 300 c.p.s.) whereas a normal single-phase rectifier would have a ripple percentage of about 50 % at 100 c.p.s. The increase in frequency improves the effectiveness of the filter circuit by 9 times, while, since the initial ripple is 1/5th of the single-phase supply, the output of the "Noregg" becomes 45 times as easy to smooth. The output voltage wave at full load is shown by oscillogram (a) and should be compared with the output voltage wave of a normal single-phase rectifier as shown by oscillogram (b).

Full details of the "Noregg" system, and the "Westat" which is for use with batteries, are given in new descriptive pamphlet No. 11 L, a copy of which may be obtained from Dept. I.E.E.

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for use without batteries

"WESTAT" for use with batteries

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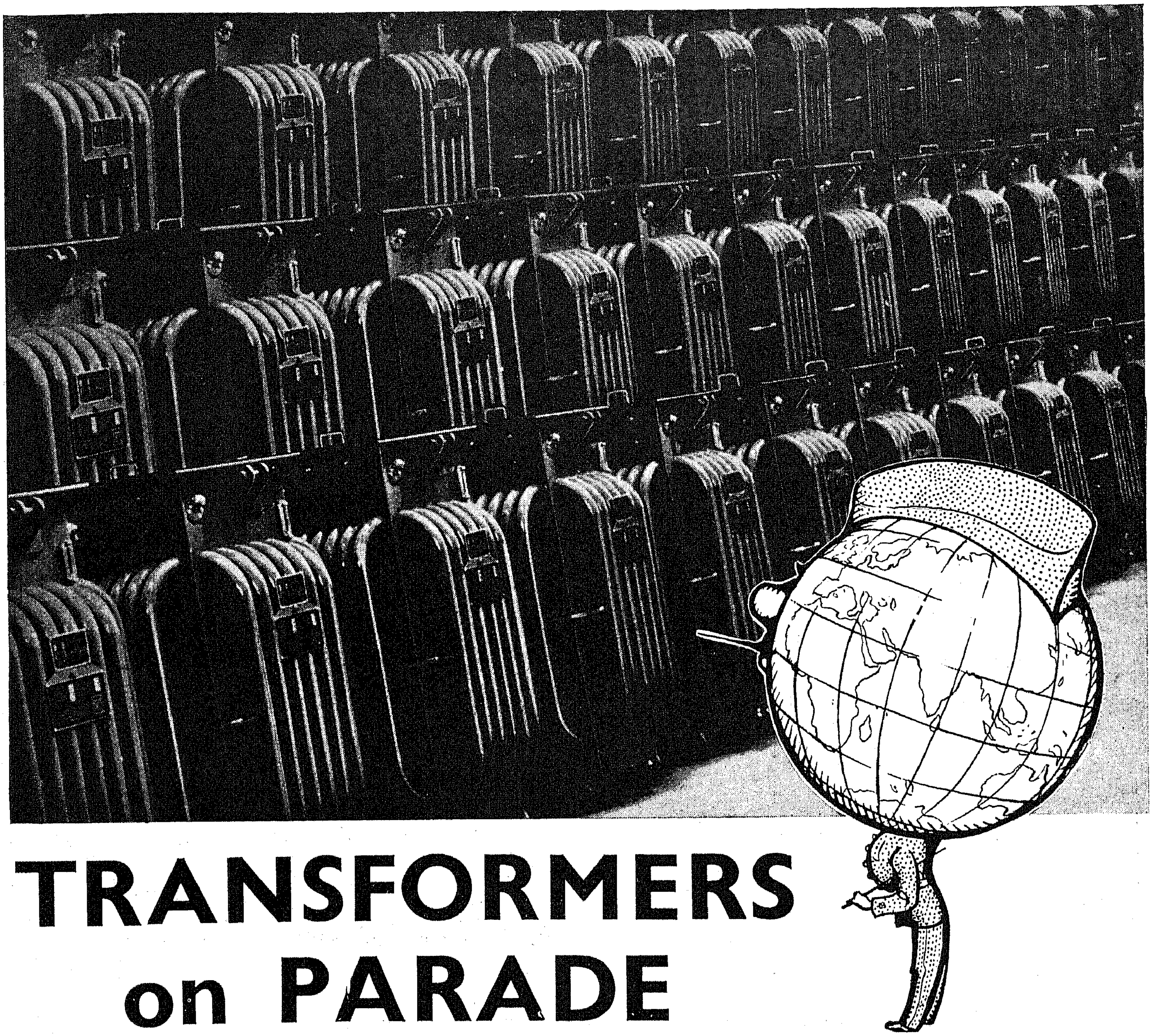

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Telephone: Walton-on-Thames 760 (8 lines). Telegrams: "Electric, Walton-on-Thames."

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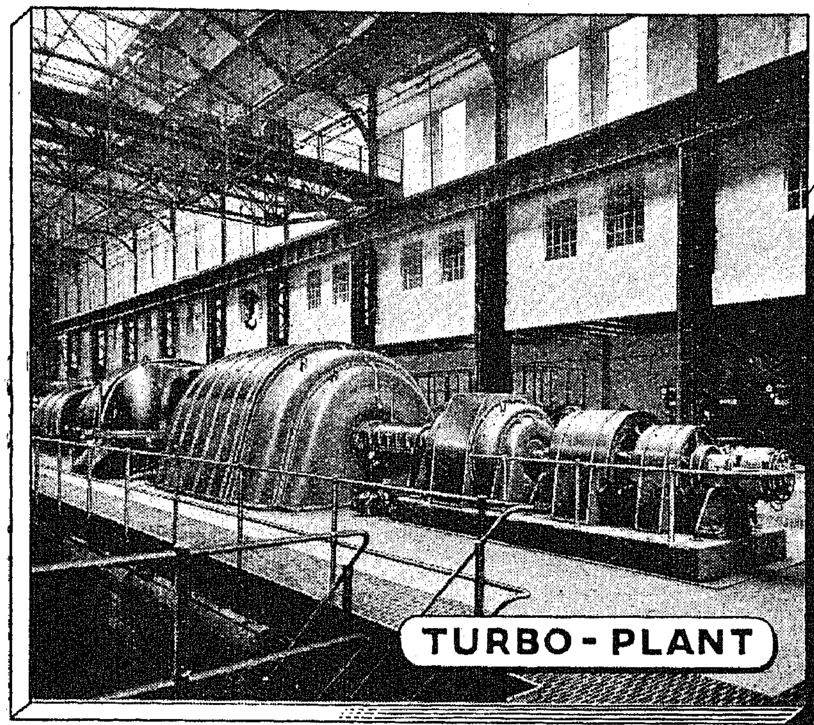

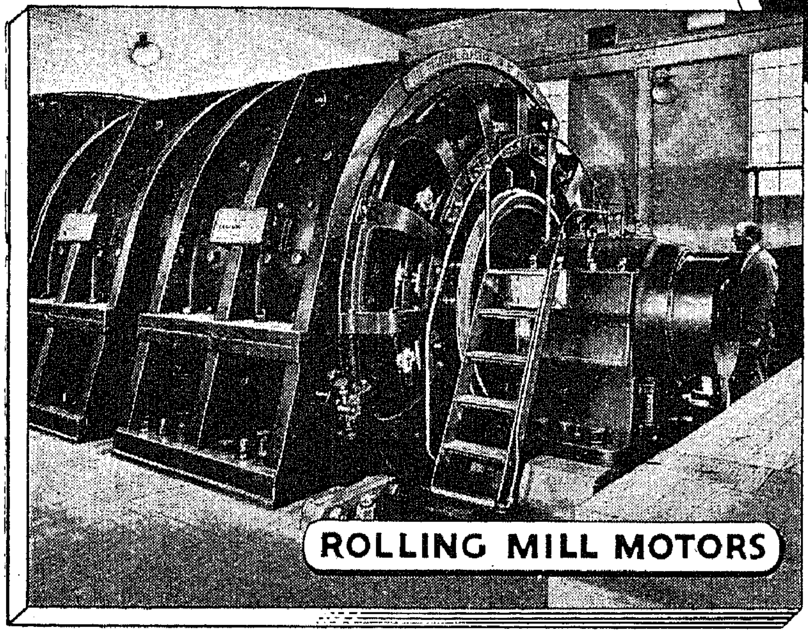

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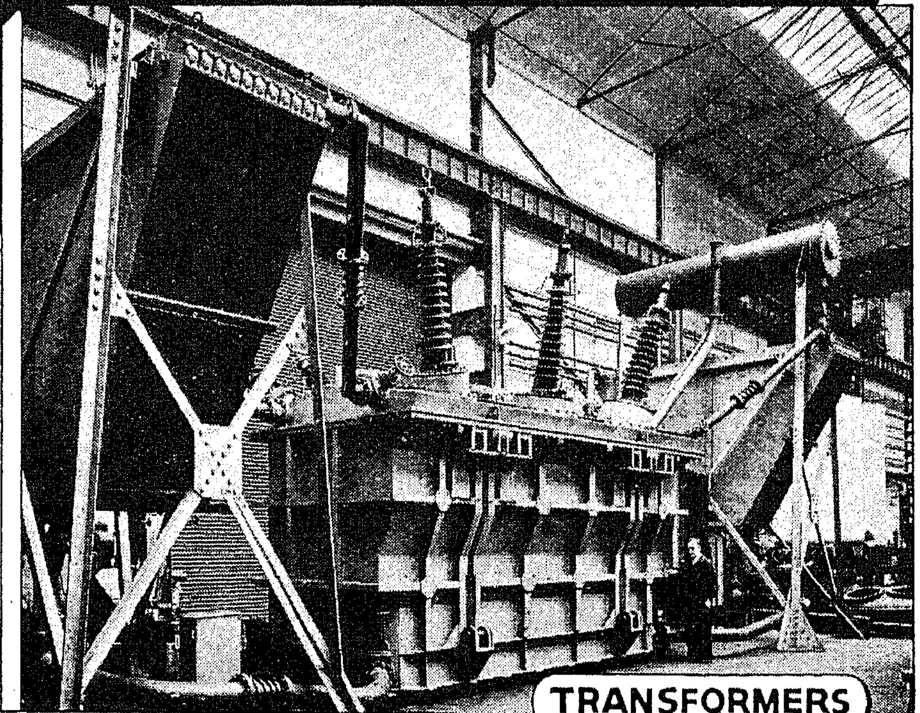

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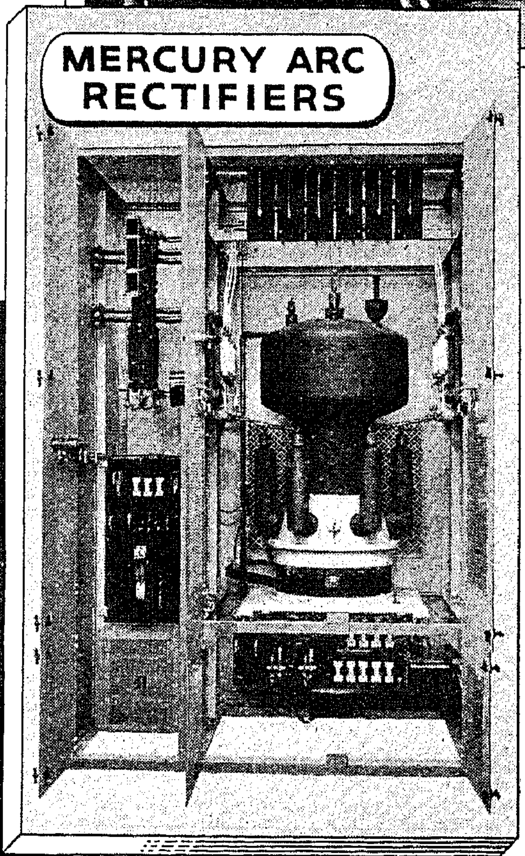
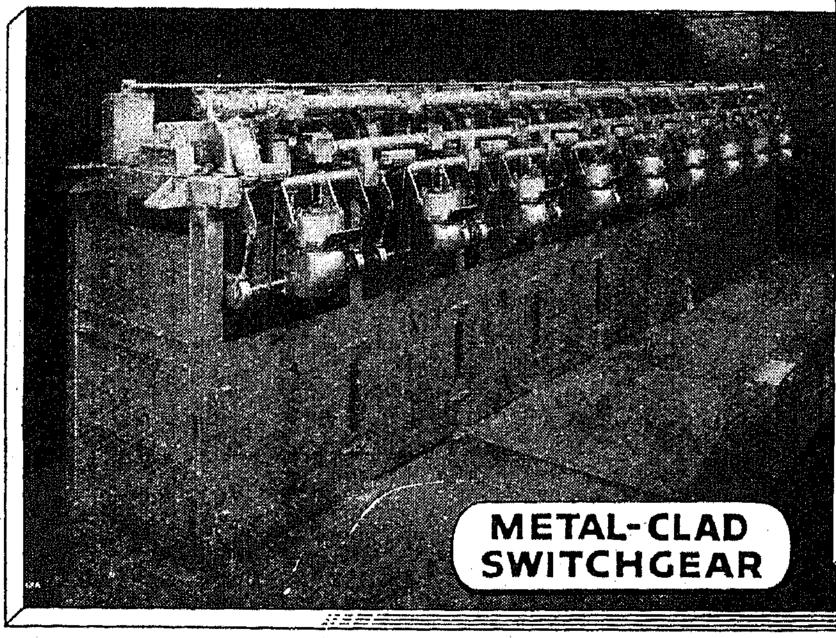


A pumpless air-cooled steel-clad Mercury Arc rectifier for installation underground in a South African mine.



11 KV 1,000,000 KVA metal-clad switchgear for a Scottish Undertaking.

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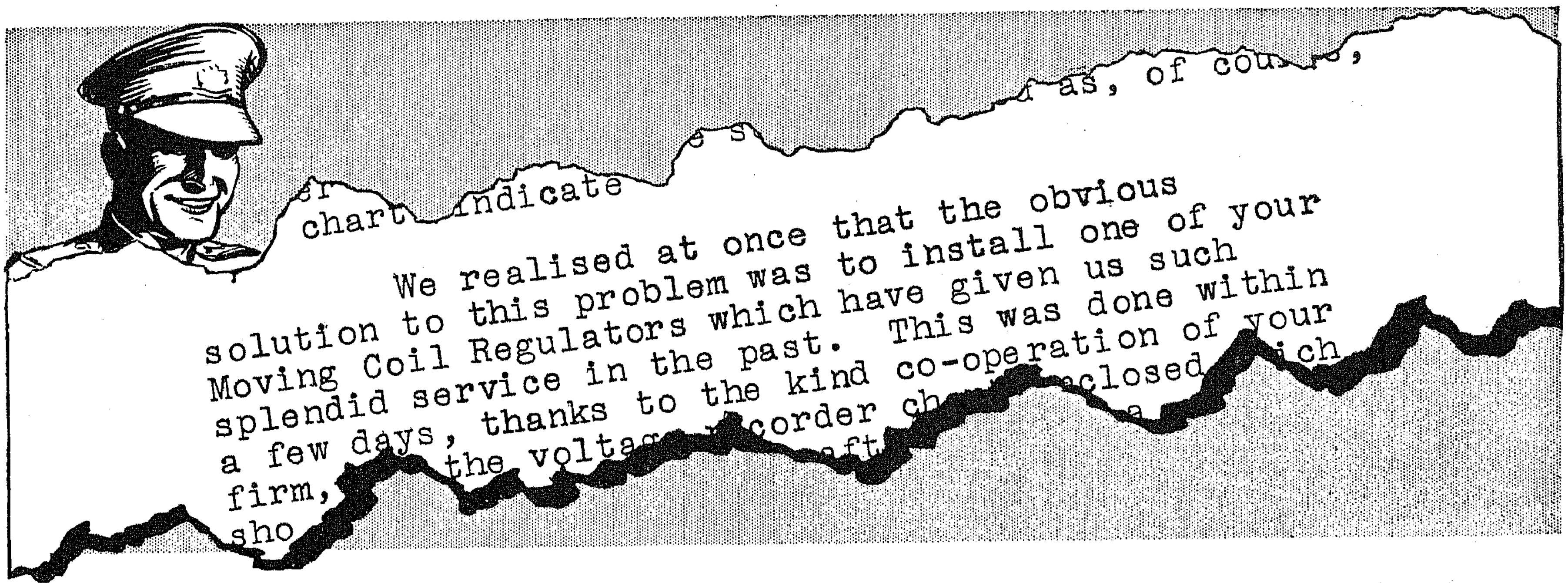

...as, of cou...

...chart indicate

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A local hall, he writes, was recently taken over by the Military Authorities. They decided to cook by electricity, and pressure troubles of a very serious nature were soon experienced, as the attached chart indicates.

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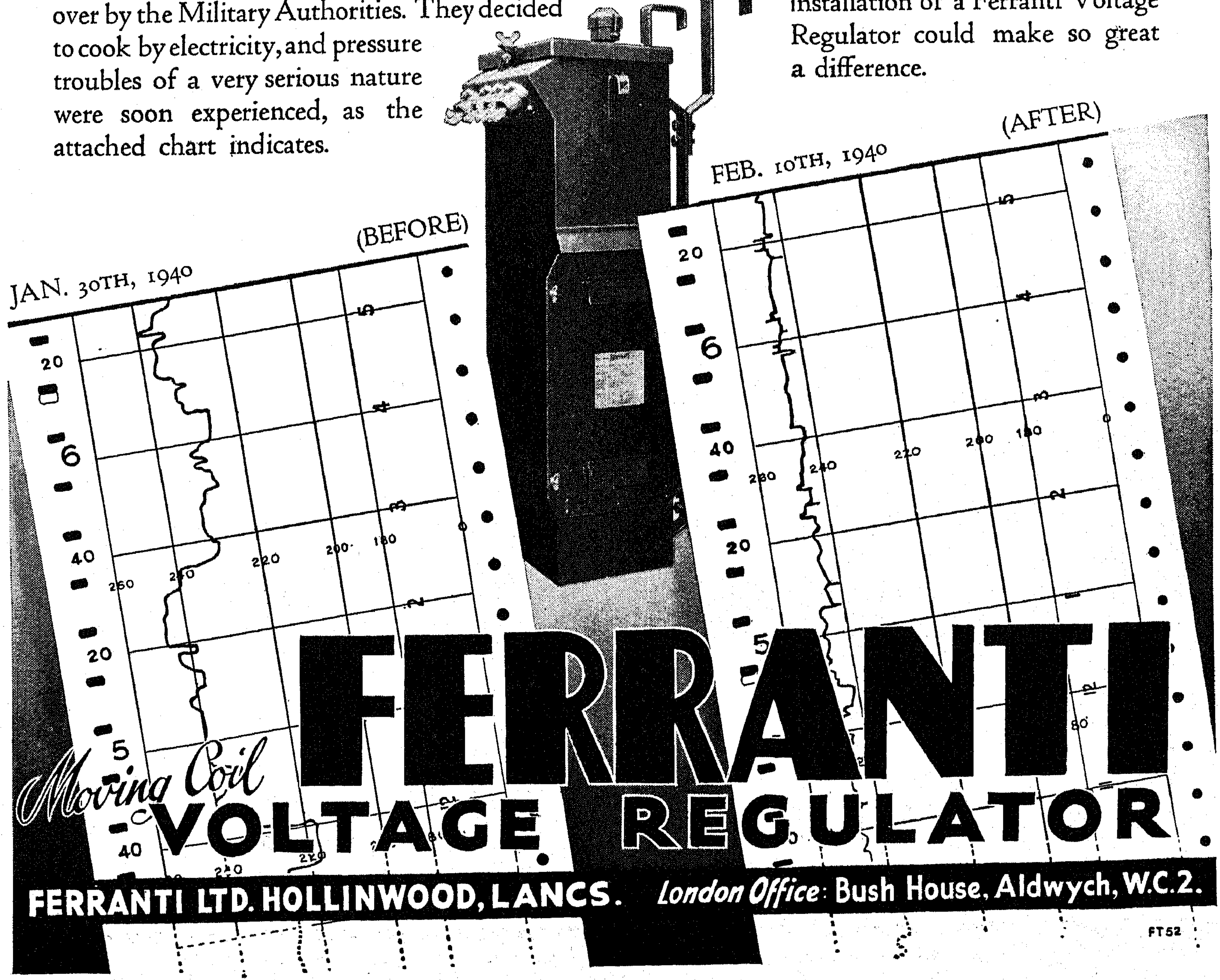

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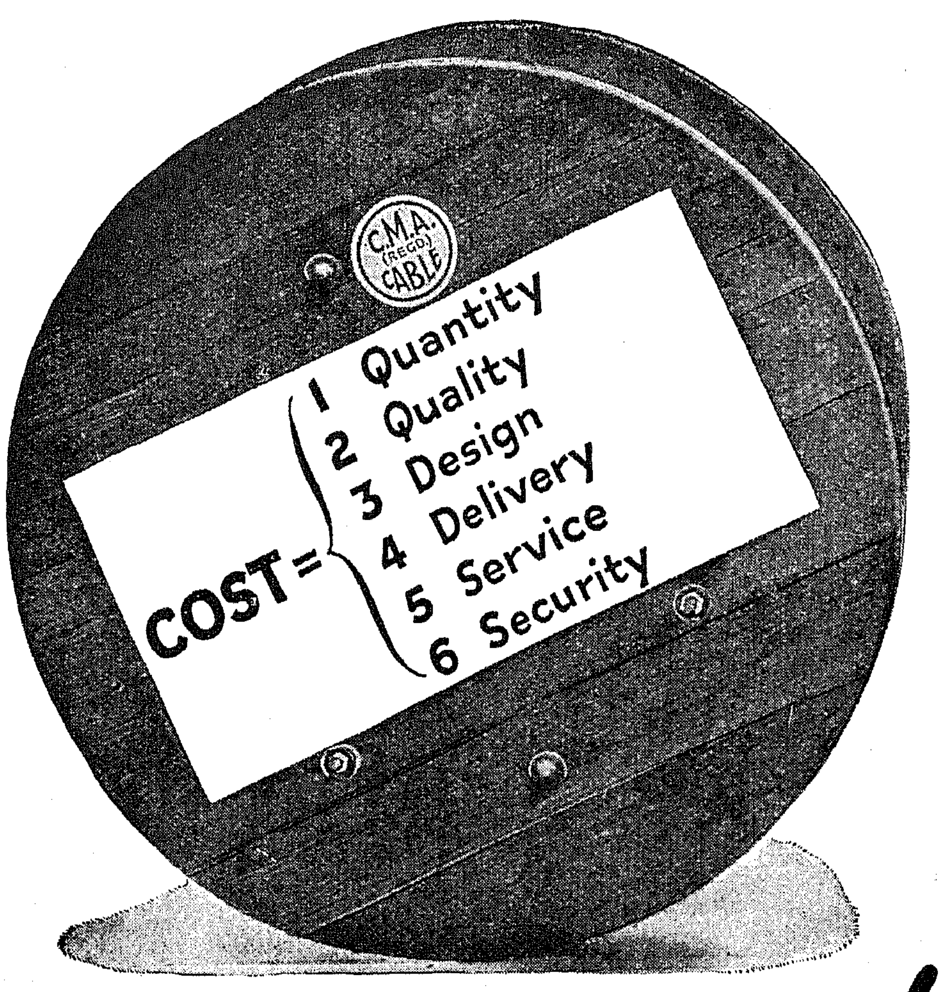
Moving Coil **VOLTAGE REGULATOR**

FERRANTI LTD. HOLLINWOOD, LANCS. *London Office*: **Bush House, Aldwych, W.C.2.**



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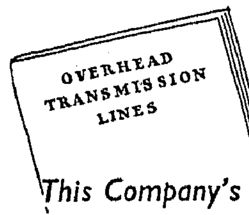

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P 19. I.E.E J. 9. 40

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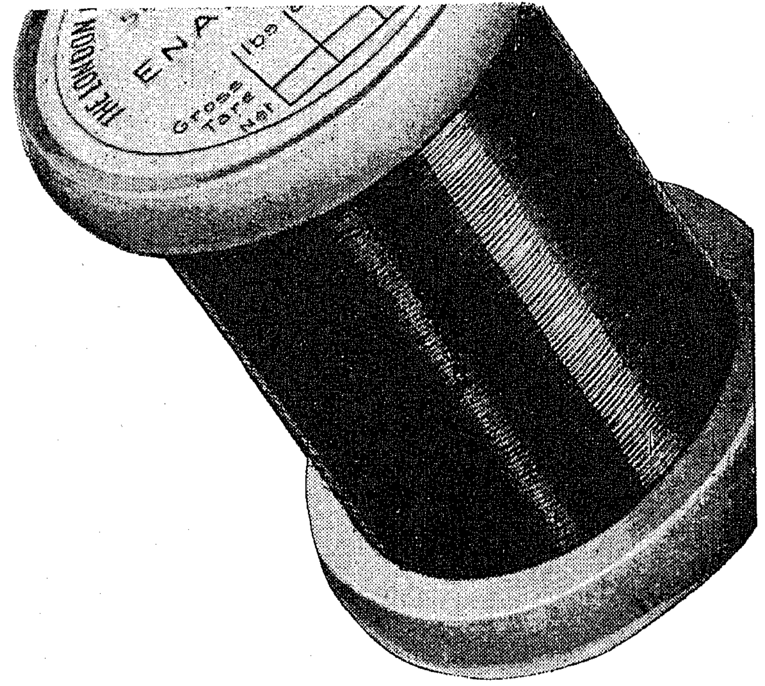

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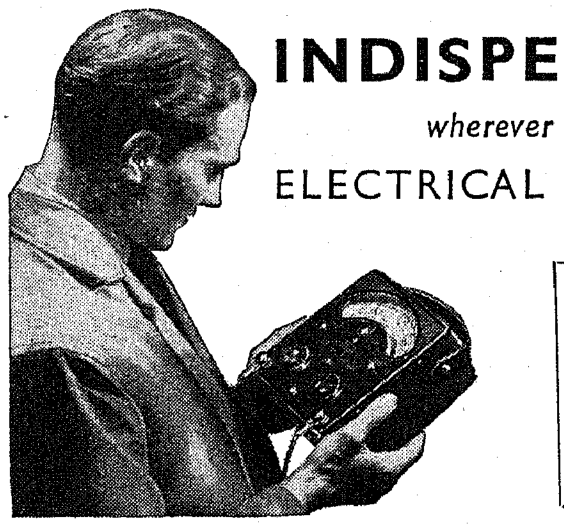
THE LONDON ELECTRIC WIRE COMPANY AND SMITHS, LIMITED, CHURCH ROAD, LEYTON, LONDON, E.10



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One Instrument
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Current, A.C./D.C.
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Resistance
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Audio-Frequency
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Also available–
Model 7 Resistance Range Extension Unit (for measurements down to 1/100th ohm).
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AVOMETER
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Electrical Measuring Instrument *Model* 7

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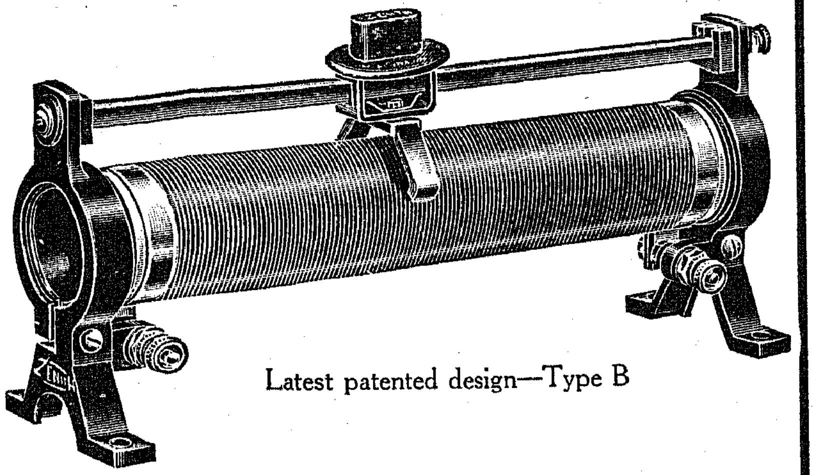

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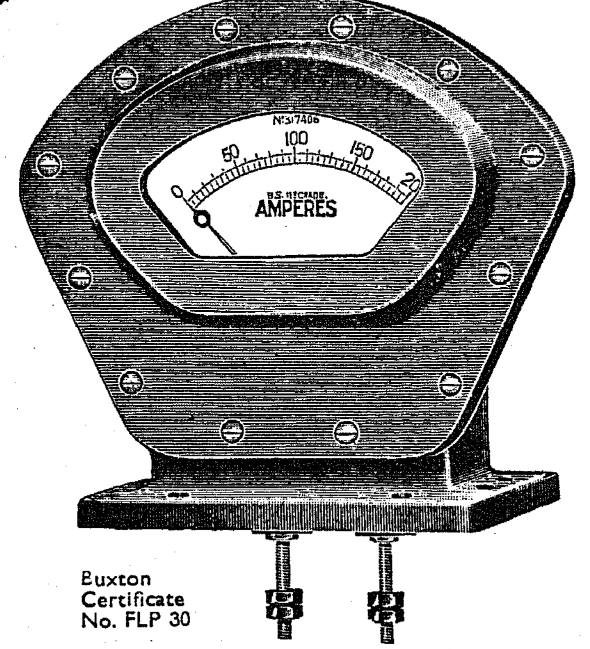

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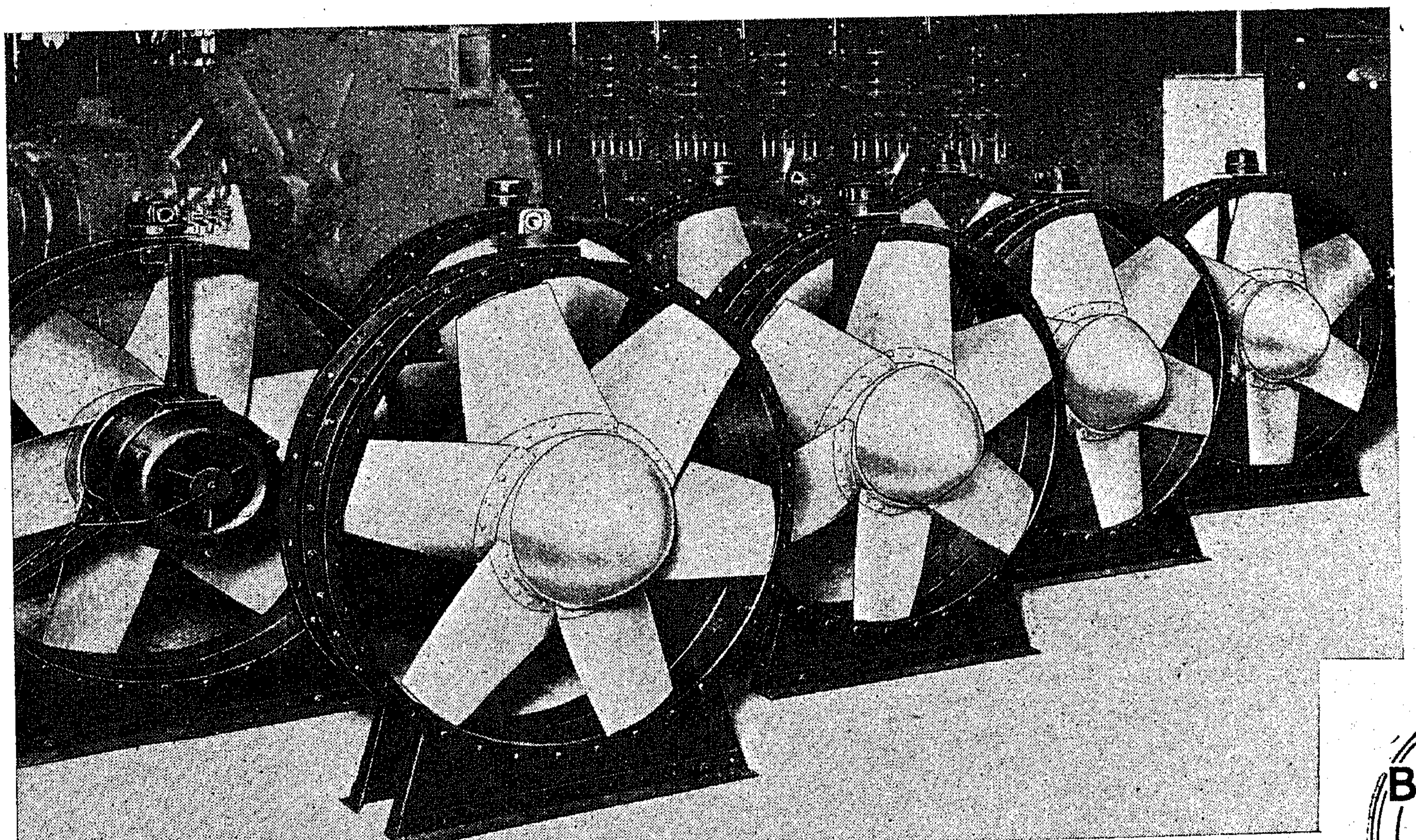

These "Blackman" Anti-clastic Propeller Fans are axial-flow type designed for work hitherto done by centrifugal fans, work which involves the movement of considerable quantities of air against moderate resistance, through trunking, etc. With them simpler ductwork is permissible, with consequent lower first and running costs, due to lower pressure losses.

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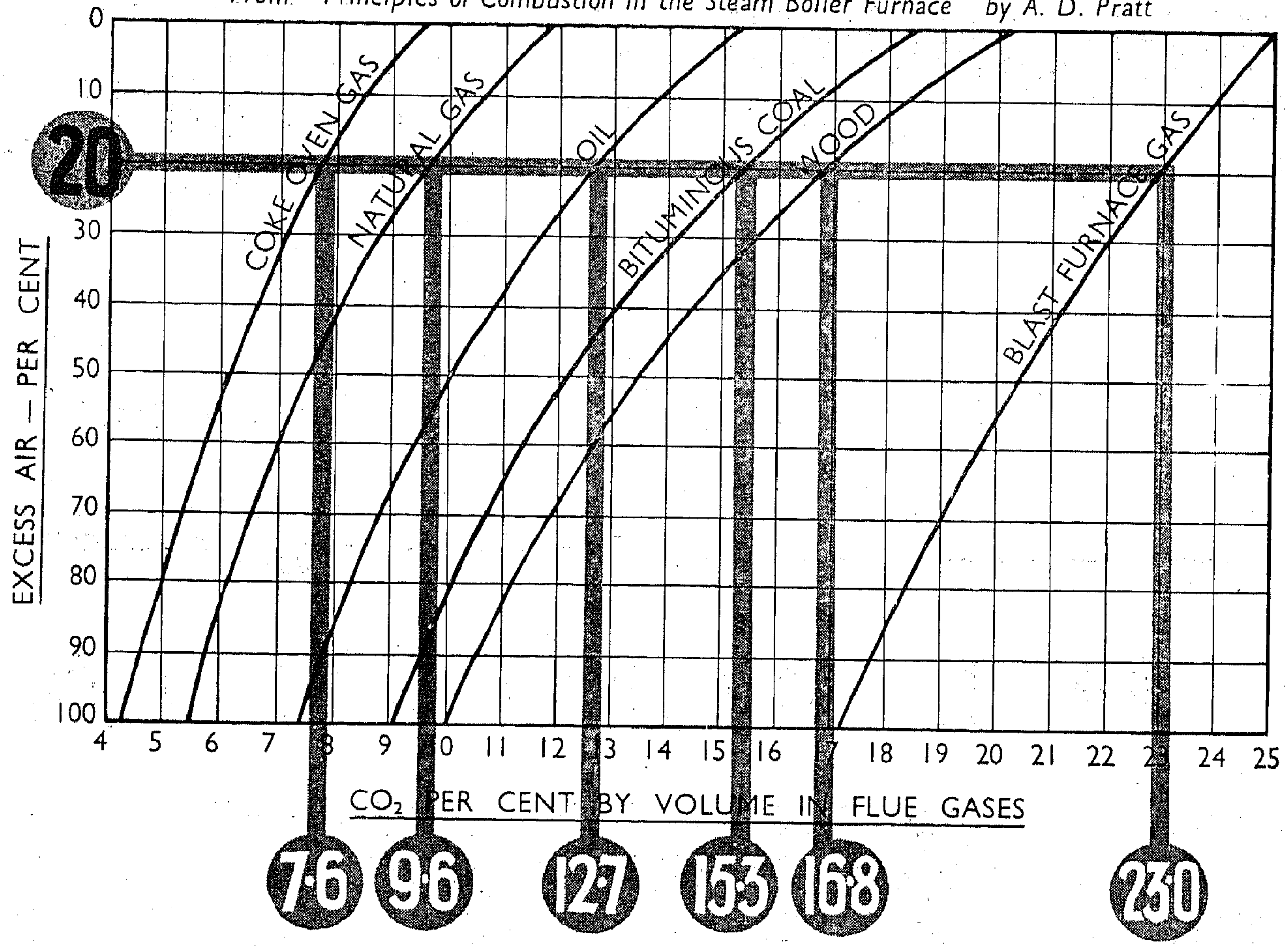
If it's HEATING, VENTILATION, DUST EXHAUST, INDUCED DRAUGHT, DRYING —or any other proposition involving movement of AIR or GASES, consult us

WHAT DOES CO_2 MEAN?

Relation Between Excess Air and CO_2

From "Principles of Combustion in the Steam Boiler Furnace" by A. D. Pratt



THE percentage of CO_2 for the same amount of excess air varies according to the analysis of the fuel.

Bailey Water Cooled Furnaces have been installed for all the fuels shown in the chart above, and enable MINIMUM EXCESS AIR to be maintained over a very wide range of load.

This is the first of a series of three advertisements

BABCOCK & WILCOX LTD. 34 FARRINGDON STREET
LONDON, E.C.4

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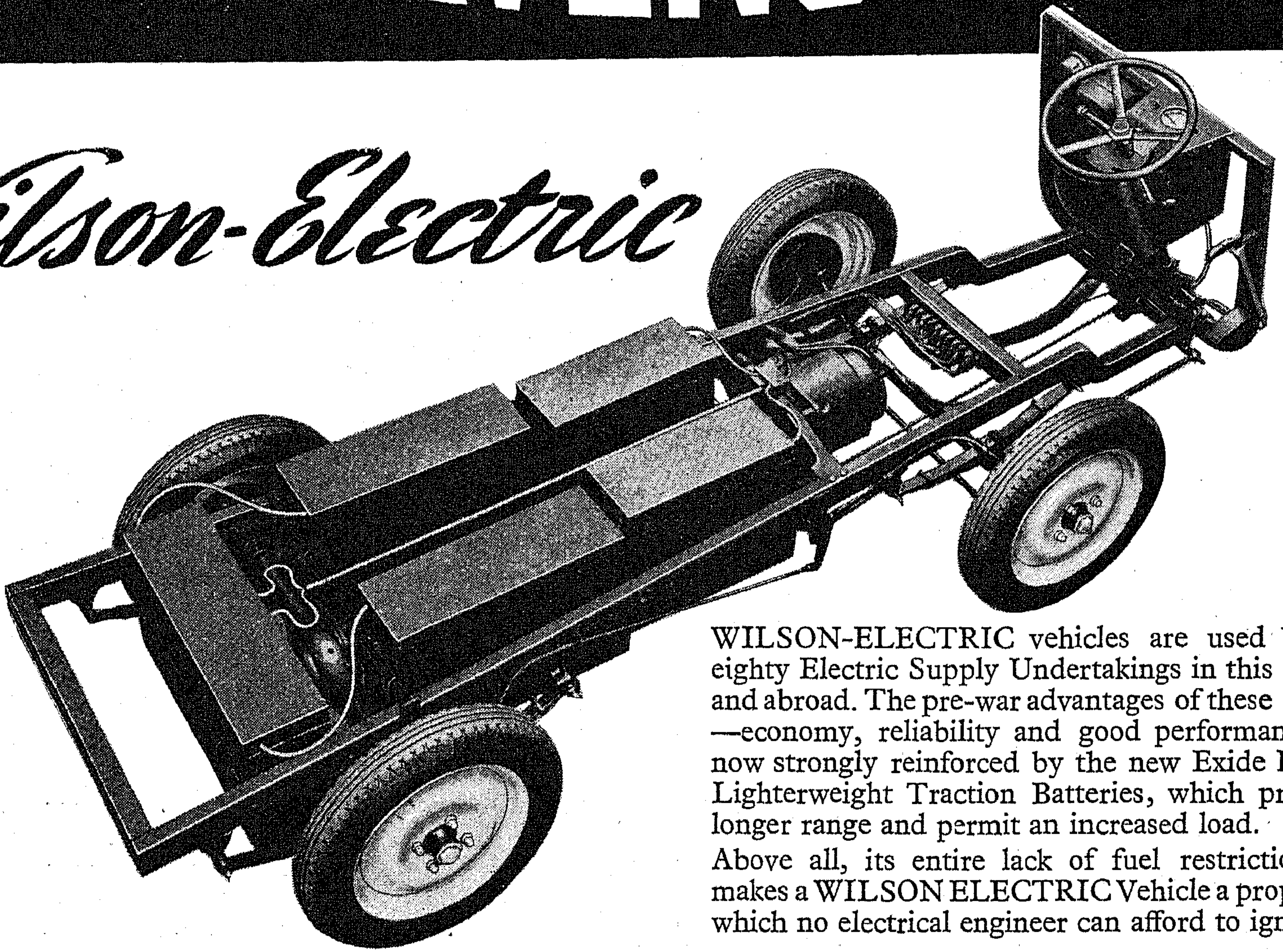
DAVENSET

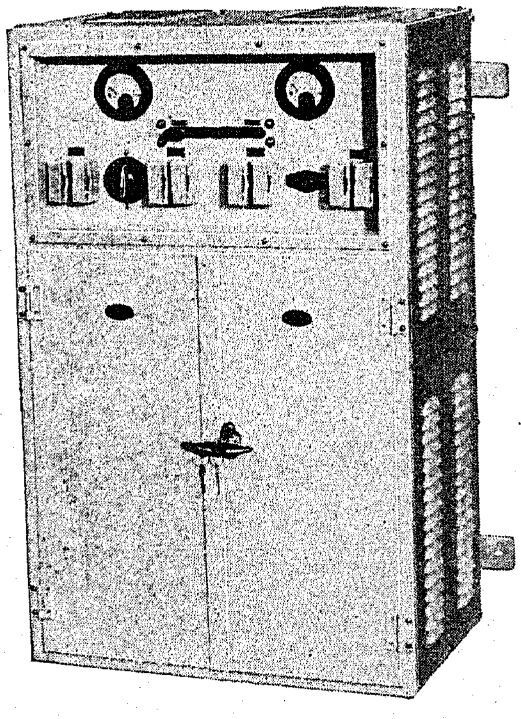
Wilson-Electric



WILSON-ELECTRIC vehicles are used by over eighty Electric Supply Undertakings in this country and abroad. The pre-war advantages of these vehicles—economy, reliability and good performance—are now strongly reinforced by the new Exide Ironclad Lighterweight Traction Batteries, which provide a longer range and permit an increased load.

Above all, its entire lack of fuel restriction now makes a WILSON ELECTRIC Vehicle a proposition which no electrical engineer can afford to ignore.

DAVENSET DRIMET METAL RECTIFIERS



are individually designed and produced to suit all types of requirements. Fourteen years of specialisation in rectifiers and battery charging apparatus enable us to offer equipment in the most practical form, to satisfy the most exacting demands.

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provide the ideal equipment for cellar-draining and sump-clearing purposes. They are entirely self-contained, the float and switch mechanism being enclosed in the main housing, so that installation is rapid and simple. Complete submersion does not affect their operation. Approved by Home Office for Air Raid Shelter drainage.

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